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155-mm ARTILLERY REARM MODULE WITH LIQUID PROPELLANT, PHASE I

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13. ABSTRACT (Maximum 200 words)

A summary of the concept study and preliminary design for an improved 155-mm artillery rearm module (ARM) is presented. This module is to be an improvement over a 155-mm ARM designed, fabricated, and tested under previous contract (DAAA21-88-C-0161). The trade-off study effort involving liquid propellant (XM46) handling and storage concepts is discussed. The rearranging of the projectile handling magazines developed under previous contract (DAAA21-91-C-0082) is also discussed. The preliminary design of the configuration selected on the basis of the trade study is presented.

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CONTENTS

CONTENTS (cont)

CONTENTS (cont)

TABLES

FIGURES

FIGURES (cont)

INTRODUCTION

This document is the Phase I Final Report for the 155-mm Artillery Rearm Module with Liquid Propellant (ARM II/LP) program. This two phase program was awarded to General Electric Armament Systems Department (GE-ASD), Burlington, VT on 11 March 1993 by the U. S. Army Armament Research, Development and Engineering Center (ARDEC), and is sponsored and managed by PM-FARV, Picatinny Arsenal, NJ. GE-ASD, being a department of GE Aerospace which merged with Martin Marietta in April 1993, is now Martin Marietta Armament Systems, which has assumed all assets and obligations of GE-ASD including the ARM II/LP program.

The ARM II/LP program requires concept studies and subsequent development of a proof-of-principle artillery rearm module capable of delivering both 155-mm projectiles and XM46 Liquid Propellant (LP) to a surrogate rearm port simulating a future field artillery system. The ARM II/LP ammunition delivery system is derived from the ARM II/Unicharge system currently under development by Martin Marietta for PM-AMMOLOG. The significant distinction between these two systems is that ARM II/Uni will resupply projectiles and XM230 unicharge propellant whereas ARM II/LP will resupply projectiles and LP. Both systems represent a second generation of artillery resupply technology following the original ARM development (retroactively named ARM I) which successfully resupplied unfuzed 155-mm projectiles and 155-mm propelling charges (cloth bag type in their steel container packaging).

Phase I - Concept Development is complete and covers a period from March 1993 to August 1993. This phase consisted primarily of an LP study and the formulation of a preliminary design approach. The findings of the LP study were used to guide the development of a safe and effective LP resupply concept, and are also documented in an unpublished report under separate cover. The recommended ARM II/LP concept includes:

- A single 250 gallon LP storage tank with a 50 gallon per minute centrifugal pump and automated plumbing network.

- Two side-by-side independently driven projectile magazines with 1:1 access and high speed search.

- Electronic control system with software to operate the system and manage cargo inventory.

- A 2-D matrix label reader automatic munition identification system.

- A manually deployed swing-out and extendible transfer conveyor with precision docking head and integral LP coupling.

- A palletized structure for adapting the system to a Bradley MLRS carrier.

- A system for uploading LP from 30 gallon HAZMAT drums.

- A surrogate port to mate with the conveyor docking head and receive LP and projectiles for system demonstration.

The preliminary design for this concept was developed during Phase I and presented at a Preliminary Design Review held at ARDEC on 29 July 1993.

Since most[1] of the non-LP portion of the ARM II/LP concept is similar or identical to ARM II/Uni hardware, conceptual design of these components was unnecessary and detail design, which is a Phase II activity, was authorized to proceed in parallel with Phase I. Specific Phase II detail design tasks initiated during this period were the projectile magazines, non-LP electrical controls, munition identification, transfer conveyor and vehicle interface structure.

DESIGN REQUIREMENTS

During Phase I of the ARM II/LP program, a list of system design requirements was derived from the statement of work, prior ARM programs, customer requests and mission analysis. The system requirements were subsequently allocated to various subsystems and individual components through the process of functional decomposition. Near the end of Phase I, the requirements list was translated into a formal system specification, (Martin Marietta Specification #A10040), and submitted to fulfill the requirements of CDRL A023.

The following is a summary of the ARM II/LP system design requirements. The complete system requirements specification is contained in the Prime Item Development Specification (CDRL A023).

ARM II/LP System Definition

The ARM II/LP shall be a projectile and liquid propellant storage module proof-of-principle demonstrator for future field artillery rearm operations.

In a projectile upload operation, projectiles are manually placed onto the ARM II/LP transfer conveyor. The transfer conveyor shall carry the projectiles into the ARM II/LP where they shall be automatically identified and handed off to one of two projectile magazines.

In the manual projectile download operation, projectiles shall be automatically handed off from the magazine to the transfer conveyor. The transfer conveyor shall bring the projectiles out of the ARM II/LP for manual removal. In the automatic projectile transfer operation, the transfer conveyor shall deliver/accept 155-mm rounds to/from a surrogate rearm port.

Uploading LP into the ARM II/LP shall be accomplished by drawing LP from HAZMAT supply drums into an onboard storage tank. Downloading LP to HAZMAT drums shall be accomplished through a combination of draining and/or pumping LP from the storage tank. Transferring LP between ARM II/LP and a surrogate port undergoing resupply or download, shall be accomplished by pumping LP to/from the storage tank through a flexible hose that is integral with the transfer conveyor. Control valves shall allow the same onboard pump to serve the uploading, downloading, and transfer operations.

ARM II/LP operation shall be under control of an electrical control system. The electrical control system shall also maintain onboard inventory information for both projectiles and LP.

The ARM II/LP shall utilize two projectile storage magazines mounted side by side at the forward end of the Bradley MLRS M987 chassis bed. The LP storage module shall be aft of the projectile storage module. The transfer conveyor shall be hinged at the forward end of the projectile storage module and shall swing outward, perpendicular to the left side of the vehicle, during normal operation. For transport, the transfer

conveyor shall swing aft and stow against the left side of the system.

Environmental Requirements

1. The ARM II/LP shall be capable of meeting all operational performance requirements when parked on terrain with up to 20% side slope and 20% grade. In addition, the system shall be transportable over terrain with up to 40% side slope and 60% grade.

2. The ARM II/LP shall meet all performance requirements with ambient temperatures ranging from 32° to 125°F.

3. The ARM II/LP shall be resistant to water spray, sand, dust, rain, humidity, vibration, shock, solar radiation and electromagnetic radiation, as detailed in Martin Marietta Specification #A10040.

Interface Requirements

1. A M987 Bradley MLRS carrier chassis shall be used as the host vehicle for ARM II/LP.

2. For automated transfer the ARM II/LP shall interface with a surrogate port.

3. For manual transfer and projectile upload operations the ARM II/LP shall interface with the ground, various existing cargo carriers and trucks, the existing self propelled Howitzer, and LP packaging (HAZMAT storage drums).

4. The ARM II/LP shall be capable of storing and transferring various 155-mm fuzed projectiles as properly combined and listed in the system specification.

5. Electrical input power shall be 24 volt DC as supplied by the Bradley auxiliary power subsystem.

Physical Requirements

1. As a goal, the ARM II/LP empty weight shall not exceed 6,320 pounds.

2. Storage capacity shall be 60, 155-mm projectiles with fuzes and 250 gallons of LP, minimum.

3. Projectile orientation shall be such that they are delivered to the surrogate port base first.

Functional Requirements

1. The ARM II/LP system shall be capable of simultaneously transferring both LP and projectiles to the surrogate port at the rates specified, under all specified environmental conditions.

2. The ARM II/LP shall be capable of remote selection and automatic identification of fuzes and projectiles, from coded labels, and shall maintain an inventory of onboard projectiles and LP. The ARM II/LP shall automatically check for projectile/fuze compatibility and provide an error indication if an incompatible projectile and fuze combination is found.

3. In addition to the normal LP transfer modes of operation, the LP pumping system shall provide for recirculation, draining, purging with water, and emergency dump of all onboard LP to an external tank.

4. As a goal, the ARM II/LP pumping system shall be self priming. No manual handling of containers of LP is allowed for priming. No external support equipment is allowed for priming.

Performance Requirements

1. Rearm time (for 60 projectiles and 250 gallons of LP) shall be five minutes maximum; beginning when the docking head is connected and ending when the docking head is disconnected.

2. Projectile transfer rate (automated download) shall be 20 per minute for a full load of one type, and 12 per minute for a full load of four mixed types. LP transfer rate shall be 50 gallons/minute, minimum.

3. LP upload from HAZMAT drums shall be accomplished in no more than 30 minutes.

4. The ARM II/LP predicted mature system reliability shall be 8,000 mean rounds between failures (MRBF), minimum.

5. Scheduled maintenance shall be minimized. The design goal shall be to produce a modular system and provide adequate access for replacement of worn or failed items.

Safety Requirements

1. The operator/maintainer shall be protected from moving hardware, electric shock, pinch points, and exposure to chemicals.

2. The design shall be "fail safe" and shall provide built in test diagnostics to minimize secondary failures.

3. An emergency shower and eye wash station must be provided at all test locations.

4. Electrical components in contact with LP must be explosion proof.

5. A leak containment basin shall be provided for all portions of the LP system except the conveyor. The basin shall have full system capacity.

6. Pressure relief valves shall be provided for LP plumbing and storage tank components. Adequate provisions shall be installed in the LP hydraulic system to detect and arrest a fume off condition.

Human Factors Requirements

1. The ARM II/LP must be operable by a minimum of two and a maximum of three MOS 13B cannon crew members.

2. Operational lifting requirements are not to exceed 100 pounds.

SYSTEM DESCRIPTION

The ARM II/LP system concept consists of four major components; the projectile storage system, the conveyor system, the LP storage and transfer system, and the electrical control system; and is designed to mount on a Bradley MLRS carrier host vehicle (fig. 1). The projectile storage system consists of two magazines positioned side by side at the forward end of the cargo area, with the projectiles oriented horizontally and noses to the right. The transfer conveyor is cantilevered from the left forward corner of the left magazine, and is swung 90 degrees aft to stow alongside the system during transport. The LP storage and transfer system is located within a cabinet positioned directly behind the projectile magazines and is completely enclosed to protect the remainder of the system and the vehicle from potential spillage and leaks. The electrical control system is located in an isolated compartment on the right side of the LP system cabinet, and interconnects the vehicle, projectile magazines, conveyor, and LP system via wiring harnesses. All system components are mounted to a pallet structure, enabling the entire system to be installed and removed as a single unit. A vehicle interface structure is nested within the vehicle well to adapt the pallet to the vehicle.

Projectiles are uploaded by manually placing them onto the transfer conveyor, which then carries them to the projectile storage system where they are automatically identified and handed off into the two magazines. LP is drawn from modified 30 gallon HAZMAT drums by running the pump at slow speed to upload the ARM II/LP storage tank. For demonstration purposes, projectiles and LP are downloaded through the transfer conveyor docking head to a surrogate rearm port. Projectiles can also be downloaded manually to pallets, truck beds and current Howitzers, and LP can also be downloaded back to HAZMAT drums.

The entire ARM II/LP system concept, as it existed at the end of Phase I, is documented on drawing 10051701 which was submitted as part of CDRL A003 conceptual design drawings. Drawing 10051708 (fig. 2) depicts the planned drawing architecture at the end of Phase I, this drawing will be updated and expanded as the system detail design evolves.

Electrical Control System

The electrical control system is the set of electrical control boxes, motors, sensors, actuators, cables, human interface devices, and software required to provide an interface with the operator and to control the operation of the ARM II/LP mechanism. The major components of the electrical control system are described below and their interconnection is illustrated in Figure 3.

Electronic Control Unit

The electronic control unit contains the system microprocessor and its interfaces to the rest of the control system. This unit will be made up of a collection of printed circuit boards and a chassis which have been designed and used on other products. This approach will provide a controller with excess capacity to adapt to anticipated changes in the requirements as the system design progresses, and the use of proven hardware will reduce the risk and cost of this portion of the program.

The processor circuit card assembly contains the MIL-STD-1750 microprocessor and its system interfaces. The memory circuit card assembly contains the computer memory, including the read only memory (ROM) for program storage, the random access memory (RAM) for temporary storage, and the electrically erasable programmable read only memory (EEPROM) for nonvolatile data storage. The discrete

input circuit card assembly contains interfaces to discrete sensors with on/off signals such as switches. The discrete output circuit card assembly contains interfaces to discrete indicators and actuators which require an on/off signal. The analog I/O circuit card assembly contains the interfaces to the magazine position synchros and LP analog sensors, and produces the analog rate commands to the motor control. The serial communications circuit card assembly contains the serial interfaces to the handsets and the label reader.

Motor Controls

The motor controls will be similar to the existing ARM II/Uni digital servo amplifier. The servo low level electronics will be packaged within the power distribution box. High level units 1 and 2 will contain the servo power amplifiers. The motor control circuits will take analog rate control signals from the electronic control unit and rate feedback signals from the motor tachometers and provide the power control capability to drive the motors at the commanded speeds.

ARM II/LP has four motors under rate control, each with a separate controller. There is one rate controlled motor for each projectile magazine, one for the LP pump, and one for the conveyor.

The motor controls will be packaged so as to survive in the environments which ARM II/LP is expected to be subjected with special emphasis on temperature and heat dissipation.

Power Distribution Box

The power distribution box controls the switching of power to the various system components, the sensing and interruption of overloads, and the interruption of high level power when an emergency stop switch is pressed. The servo low level electronics is also packaged within the power distribution box.

Projectile Identification (Label Reader)

Projectile Label Data. The projectile label will contain: the national stock number (13 digits, example 1230009368278); the lot number (up to 15 alphanumeric characters, example JFH83F874-298); the projectile weight (up to 6 numeric string, example 101.28); and a condition code (1 alphanumeric character).

Fuze Label Data. The fuze label will contain: the national stock number (13 digits); the lot number (up to 15 alphanumeric characters); and a condition code (1 alphanumeric character).

Performance. The label reader will utilize the same 2/D matrix technology utilized on the ARM II/Uni program. The label reader is a fixed scanner which reads encoded labels as the projectile (with or without fuze installed) moves through its scanning range. The information is automatically read with the projectile/fuze in any angular position (about the projectile center line). A multiple number of labels are printed onto an adhesive band which is wrapped around the projectile body and fuze housing. If the identification label is missing or unreadable on the projectile or fuze, or if the fuse is absent, the projectile will be loaded and "unknown" will be recorded in memory for the projectile and/or the fuze.

LP Sensors and Actuators

In addition to the LP pump motor, the following sensors and actuators are

included on the LP subsystem.

Motor Controlled Valves. A combination of five motor controlled valves provide control of LP flow within the LP subsystem. Limit switches on the valves will provide the electronic control unit with feedback of valve positions. Valve positions will be set as a function of operating mode, and correct position verified prior to operation of the pump.

HAZMAT Port Solenoid Valve. To provide fail safe closure of the HAZMAT port, a spring return solenoid valve will be utilized to enable flow through the HAZMAT port.

Priming Pump. A priming pump provides a means of priming the system when the LP level falls below the LP pump's priming well level. The priming pump is controlled via a switch on the maintenance control panel.

Tank Low and High Level Switches. Level switches are provided at the low and high tank levels to ensure that pump operation is inhibited beyond the limits of the tank. The low level is the zero reference for tank inventory control. The level switches utilize an optical refraction technology to detect the LP fluid level.

Drum Level Sensor. The drum level sensor data is utilized by the electronic control unit to prevent over filling HAZMAT drums during a download or drawing air into the LP system from an empty HAZMAT drum while uploading. The drum level sensor utilizes ultrasonic technology to sense the LP level in the drum.

Level Sensor. The LP inventory is monitored by a level sensor in the tank which utilizes the RF admittance principle. The quantity of LP transferred is determined by the difference in measurements before and after the transfer is complete and all tank turbulence has settled.

Flow Meter. The flow rate of LP during pumping is monitored by the flow meter utilizing magnetic inductive flow sensing technology. The flow data is integrated to monitor volume transferred while pumping is in process to determine the correct pump shut-off point for the desired transfer volume. The flow data is also used as the feedback signal for the flow rate control loop used during LP download modes.

Pump Inlet Pressure Sensors. In upload modes of operation, the pump control loop will maintain a constant vacuum at this sensor location. If vacuum exceeds the control loops ability to maintain control, the upload will be interrupted and a plugged line or empty drum condition will be assumed. If the data collection mode is active, this data will be reported to an external recording device via the test RS-232 port.

Docking Head Interlock Switch. The docking head interlock switch will be utilized to prevent the system from entering LP modes using the docking head until docking is complete.

Surrogate LP Ready Sensor. The surrogate LP ready sensor will interlock all upload and download of LP via the conveyor until the surrogate system is ready for transfer. A magnetic reed switch will be utilized to sense a magnetic field generated by the surrogate port when it is ready for transfer.

Audio Alarm. A two tone audio alarm will alert the crew of any hazardous condition detected. The alarm will be activated according to the emergency procedures. The alarm will have two different sounds indicating a level 1 or level 2 emergency.

Visual Alarm. A visual alarm will alert the crew of any hazardous condition during a level 1 or 2 emergency.

LP liquid Sensor. Presence of LP in the drip basin will initiate a level 1 alarm condition.

Smoke Sensor. An ionization smoke detector will be located in the LP tank vent to detect a LP fuming condition. Detection will cause the electronic control unit to halt all pump operations, set valves, and activate alarms as specified in the emergency procedures. If the ARM II/LP system is off, the smoke detector will activate level 1 alarms via system battery power.

Tank Temperature Switch. The tank temperature switch will activate the level 1 alarms via battery power if excessive tank temperature is detected.

Temperature Sensors. Temperature sensors are located at the pump outlet, pump inlet, pump priming well, tank bottom, tank middle, tank top, and each of three trapped pipe sections between potentially closed valves. If a temperature is greater than 180°F, pump operation will be software inhibited, and valves and alarms will be set as defined in the emergency procedures. If data collection mode is active, data will be reported to an external recording device via the test RS-232 port.

Pressure Sensors. Pressure sensors are located at the pump outlet port and trapped pipe sections between potentially closed valves. If a pressure is detected greater than 80 psi, pump operation will be software inhibited, and valves and alarms will be set as defined in the emergency procedures. If data collection mode is active, data will be reported to an external recording device via the test RS-232 port.

Conveyor Sensors and Actuators

In addition to the conveyor drive motor, the following sensors and actuators are included on the conveyor subsystem.

Resolver. The conveyor resolver provides absolute position of the conveyor which is utilized to control the positioning of projectiles in preparation for transfer to the projectile magazines.

Initial Timing. During an upload operation the position of the projectile on the conveyor must be sensed just prior to entering the magazine handoff so that the conveyor and the projectile location can be synchronized with the conveyor resolver data. At the conveyor rate required to meet system transfer rate requirements the conveyor must be slowed to a stop in a controlled, ramp down, manner to prevent over shooting the desired position. The initial timing sensor utilizes an optical beam technology as is used in the ARM II/Uni system.

Limit 1 and Limit 2 Sensors. The conveyor will contain two pairs of limits switches utilized to ensure proper positioning of projectiles prior to transfer into either projectile magazine. For proper positioning, the base of the projectile must be past the limit 1 sensor and covering the limit 2 sensor. All limit sensors will utilize optical beam sensor technology as utilized on the ARM II/Uni system.

Collision Avoidance and Load Tray Sensors. During a download operation when a projectile is left on the conveyor load tray and another projectile is approaching on the conveyor, the conveyor will be stopped to prevent a collision between the two projectiles. To control this function a mechanical switch is built into the load tray

support so that it is actuated when there is weight on the load tray. Another sensor will be located on the conveyor between the conveyor belts to sense an approaching projectile. The collision avoidance sensor will be a proximity switch sensing the metal surface of the projectile as it passes over the sensor.

Projectile Orientation Sensor. During the upload operation, when projectiles are manually loaded on the conveyor, human error allows for the possibility that the projectiles will be loaded in the wrong orientation, base first vs nose first. A reversed projectile would not be sensed and positioned properly and could cause damage to the system or the projectile. The projectile orientation sensor is a proximity sensor located just ahead of the initial timing sensor. If the projectile is nose first, the initial timing sensor optical beam will be broken by the nose of the projectile before the projectile surface is close enough to the projectile orientation sensor to be detected. If the projectile is base first the projectile orientation sensor will sense the projectile base before the initial timing optical beam is broken by the base.

Grommet Sensor. The ARM II/LP system is not capable of handling projectiles with grommets in place. To prevent damage due to operator error, the grommet sensor will detect the presence of grommets, halting the conveyor so the projectile can be removed and prepared for upload. The grommet sensor employes optical beam technology to detect the increased diameter of the projectile at the grommet.

Fuze Camera Trigger. The fuze ID camera will be triggered by the fuze camera trigger when the tip of the fuze breaks the triggers optical beam.

Conveyor Interlock Switch. A switch will be built into the conveyor deployment mechanism which will be utilized to prohibit operation of the conveyor unless it is fully deployed.

Emergency Stop Switches. The emergency stop switches provide the crew with a means to stop the (motor/conveyor) system in the event of any immediate or potential hazard to personnel or system hardware. Actuation of the emergency stop requires only a simple depression which locks the switch in a depressed position. Restarting the system after an emergency stop can only be initiated by retracting the same emergency stop switch that created the stop, and will require additional protocols (procedural verification that conditions are safe to restart the system), which are implemented and prompted via the remote handset. These safety switches are located at six positions on the conveyor, one in the crew station, and one on the maintenance panel.

Projectile Magazine Sensors and Actuators

In addition to the magazine drive motor, the following sensors and actuators are included on each projectile magazine.

Magazine Resolvers. The magazine position sensors include a synchronizer attached to each magazine in such a manner that it will rotate through one revolution as a magazine element moves through one complete cycle of the serpentine loop. The synchro output will be sent to the processor through a synchro to digital converter and will be used for magazine timing as well as identification of magazine elements for inventory control purposes.

Empty Element Sensors. The empty element sensor will sense the presence of a projectile in a magazine element. It will be used as a double check of the inventory information to prevent loading a projectile into an already full magazine element. For this purpose an inductive proximity switch will be used. This sensor will be located as

close as possible to the projectile load position to minimize timing delays.

Magazine Transfer Solenoid. This actuator will initiate the action of the magazine transfer forks and selector gate to load a projectile into or out of the magazine. The movement and timing of this transfer mechanism will be mechanically controlled and driven from the magazine motion.

Gate Interlocks. Data from the gate interlock sensors will be utilized to inhibit automatic operation when the transfer mechanism is manually activated to prevent mechanical damage to the system.

Remote Handset

The remote handset (RH) is the primary user interface with the ARM II/LP system. As shown in figure 4, the remote handset provides a control/display interface comprised of a (3 in. x 5 in.) liquid crystal display (LCD) and a numeric/ control-function keypad. The LCD is an array of 240 horizontal by 128 vertical pixels formatted to provide 16 lines of text/symbols using 40 (5x7) characters per line. Line graphics, blinking and inverse video attributes are also supported. The dedicated function keypad provides local display controls (SCROLL and PAGE), system logic controls (TAKE CONTROL, MAIN MENU, CLEAR ENTRY, and ENTER), numeric data entry (0-9, CLEAR) and system-level controls (START and STOP). These keypad functions are described in figure 5.

The display area is formatted such that the arrangement of information is consistent, regardless of the application (upload, download, menu selections, etc). The display arrangement shown in figures 6 and 7 is representative of all of the primary upload/download displays. The display areas common to all of these applications include (as a minimum):

- Menu or operational task title, centered at the top of the display.

- Menu options/data field area in the central area.

- Procedure/prompt/message area at the bottom.

- Reserved area in the upper left for the CONTROL indication.

- Single line cursor box including a caret (>) symbol to designate a selected menu option or a selected munition.

Crew Station

The crew station interface (fig. 8) is dash mounted within the Bradley chassis cab at a location between the driver and passenger positions. This unit includes an enclosure/mounting assembly that contains:

- A power ON toggle switch and indicator.

- An emergency stop switch.

- A level 1 alarm override switch.

- A (removable) remote handset.

The function of the crew station is to provide power control for the ARM II/LP system, an emergency stop capability and the ability to interrogate and/or make (limited) data entries to the ARM system. The rationale for locating this ARM interface in the vehicle cab is to enable the following in-route capabilities:

- To expedite the download process by allowing the order to be entered prior to arrival and system deployment.

- To allow interrogation of current inventories to provide information to other resupply, transport, command or user elements.

- To conduct built-in-test (BIT) or assess/coordinate maintenance needs for use at a later time/destination.

Maintenance Control Panel

The maintenance control panel (fig. 9) is not intended for use during normal upload/download operations. The function of this set of controls is to facilitate certain maintenance operations and to coordinate certain degraded (download) mode operations where a transfer (or total) power loss has been experienced. This panel contains the following controls which will be functionally described below.

Auto-Manual Mode Control. This toggle switch will normally be in the AUTO position for routine system operation. In the MANUAL position, this control enables the remaining maintenance control panel functions and inhibits system control from the crew station or remote handset.

Mode Selection. This three position rotary switch allows the selection of either of the two projectile magazines or the LP system. Only the selected magazine or the LP system will operate as dictated by the remaining controls.

Conveyor Enable. This switch will enable the conveyor along with the selected magazine in either of the magazine modes.

Conveyor Manual Direction. This three-position toggle switch determines the direction of operation (upload, download, center off) of the conveyor and selected magazine.

Rate Control. This rotary switch controls the system magazine and conveyor rates (MANUAL mode) and the cyclic rate through the system computer (AUTO mode).

Manual Rate Fine Adjust. This variable control allows for fine adjustment of system magazine and conveyor rates in manual mode.

LP Drain Enable. This switch will set all valves to the LP system gravity drain position when the LP mode is selected.

Well Full Indicator. This indicator will illuminate when the LP pump is full indicating that the priming function is complete.

Priming Pump. This momentary switch will activate the priming pump while pressed.

Emergency Stop. This control is physically and functionally identical to the other eight emergency stop switches located throughout the system.

Error Indicator. This indicator will illuminate whenever the system has identified an error condition such as a reversed projectile, activated emergency stop, etc.

Alarm Override. This switch allows the crews to turn off the audio alarm in the event of a false level 1 emergency in the LP system.

Security. All of the maintenance control panel switches, push-button, etc., except for the emergency stop, will be physically secured (via a front cover panel) and key switch to prevent unauthorized, unintentional, or otherwise undesirable operation that might be unsafe or in contention with normal system operation.

LP Storage and Transfer System

The selected concept for the transfer and storage of LP is a pumping system with a single storage tank. The pumping system consists of a variable speed, centrifugal pump with typically 1.5 in. diameter plastic piping and motor driven valves. Operating speeds are relatively low. The surrogate rearm port contains a simplified version of the LP system and includes a storage tank, a flexible hose, and plastic piping and valves.

Pressure transducers, temperature sensors, and relief valves are located in each potentially pressurized section of plumbing and are constructed of various compatible stainless steels, elastomers, and plastics. A single storage tank, made of polyethylene, offers the simplest mechanization approach and includes several safety features.

The LP system also includes provisions to contain any inadvertent LP spillage and/or personnel exposure due to leaks or pipe bursts. To that end, the tank, pump, and plumbing are surrounded by an enclosure which includes a containment basin beneath the LP system. Figure 10 shows the LP transfer and storage system.

LP Transfer System

The LP transfer system consists of the LP pump and the entire plumbing network needed to interconnect the LP storage tank, the surrogate rearm port, and the LP loading system. Components are predominantly of non-metallic construction. LP flow is controlled by motorized ball valves. Within the transfer system a recirculation line allows air purging and system checkout prior to LP delivery, and drain lines provide for complete system purging. An emergency dump line with a motorized valve will allow the rapid offloading of LP to a controlled external storage tank for dilution and cooling in the event of a fume-off within the storage tank.

A secondary pump is used for initial system priming or for re-priming whenever the main pump has been drained for maintenance. Pressure relief valves as well as pressure and temperature sensors will be utilized in each potentially closed pipe section. In the unlikely event that a LP reaction should initiate within the plumbing, a final pressure relief is provided by the plastic piping which will burst at about 600 psi. A normally closed solenoid valve at the HAZMAT drum port will prevent LP spillage through the HAZMAT drums in the event of power loss. The LP transfer system is shown in figures 11 and 12.

Pumps. A self-priming centrifugal pump with stainless steel wetted parts and mechanical shaft seals is selected as baseline for the ARM II/LP system. The pump and impeller size will provide a flow rate of at least 50 gpm and an outlet pressure of approximately 35 psi. The selection of a centrifugal pump was based on the lower risk of adiabatic compression as compared to positive displacement pumps; ability to operate dry; and temperature compatibility with ARM II/LP as well as FARV requirements. Cost,

weight, and size are on the lower end; technology is off-the-shelf.

Some of the disadvantages inherent to this pump are the mechanical seals and the need for initial priming. Mechanical seals pose a potential for leaking and shear heating; however, the technical risk associated with this is considered minor. To prime a completely dry system, a secondary priming pump was chosen as the method since the alternative was filling the priming well of the pump by hand, which is considered unacceptable.

The automatic initial priming method is performed by a peristaltic pump connected to the centrifugal pump outlet and piped to the storage tank. This pump will provide a vacuum to lift LP from a HAZMAT drum to the pumping chamber of the centrifugal pump. It should be noted that this operation is only required when the system is completely purged of LP.

Valves. The primary valves directing the flow of LP in the system will be two-way or three-way motorized ball valves constructed of compatible plastics and elastomers. These valves feature a cycle time of ten seconds, manual override, and limit switches to determine position. The LP system also includes a solenoid actuated globe valve in the HAZMAT drum port as well as manual two-way ball valves, all of which are fabricated with compatible plastics and elastomers. The operating temperature range is 0° to 150°F.

Low pressure proportional relief valves were selected for use in each potentially closed pipe section. A manual override is provided for draining. Materials of construction are 316 stainless steel with compatible seals. The operating temperature range is -10° to 250°F.

Piping and Fittings. Plastic pipes and fittings will be used because of inherently low burst pressures (400 to 800 psi), which provides fail-safe pressure relief, and excellent LP compatibility. Water hammer effect is also more benign with plastic piping. For best leak control, pipes and fittings will be thermally bonded and will include true unions and flange unions at valves, sensors, and crosses for ease of disassembly. The selected material is PVDF plastic, which provides an operating temperature range of -40° to 300°F.

Flexible Hoses. Flexible hoses will be used in the extendible conveyor and in the HAZMAT drum port. The hose type selected has a low burst pressure (500 psi) and is rated for vacuum service. The material in contact with LP has proven compatibility. Hose end fittings are made of stainless steel with O-ring face seals. Operational temperature range is -40° to 300°F.

Quick Disconnects. Quick disconnect couplings will be used at the docking head and at the HAZMAT drum connection. The docking head quick disconnect is a special design and requires a force of 80 lbs. to connect, which is provided by an electric actuator. The HAZMAT drum quick disconnect is self-locking, requires 30 to 40 pounds to connect, and is operated by hand. Both couplings offer minimal flow resistance and a maximum spillage upon disconnection of 0.04 cc. The materials of construction are stainless steel with compatible seals. These quick disconnects are rated for operation between -4° and 167°F.

Flow Meter. The flow meter selected operates on the electromagnetic flow principle (Faraday effect) and offers an unobstructed path to the flow. The housing is made of stainless steel lined with a compatible plastic. The electrodes are of compatible stainless steel construction. The flow meter output is used to control the pump during all

download modes. Operating temperature range is compliant with expected FARV requirements.

Sensors. Temperature and pressure sensors will be utilized in each potentially closed pipe section as well as in the pump inlet and outlet. A pressure transducer in the pump inlet will monitor suction pressure for regulating the pump speed during upload operations. A temperature sensor and a level indicator will also be placed in the pump. The temperature sensors are conventional thermocouples made of compatible materials. The pressure transducers are electronic variable capacitance sensors with LP compatible wetted components. The level indicator is an electro optic liquid level sensor with variable delay time drop-out and is LP compatible. All selected sensors satisfy expected FARV temperature requirements.

LP Storage System

Storage Tank. The storage tank is a polyethylene reservoir with pressure relief provisions (blow-off cover and possible rupture disks) to mitigate a fume-off reaction. The surrounding cabinet will provide solar shielding. The storage tank is normally vented to the atmosphere when loading or downloading LP. The tank is fully drainable since the outlet is at the bottom. High and low level sensors will inhibit pumping; a smoke detector and three temperature sensors will indicate an abnormal condition within the storage tank and initiate an emergency procedure. The LP storage tank is shown in figure 13.

LP Inventory. Inventory control will be based on the tank level sensor readings taken before and after deliveries. The tank level sensor operates on the RF admittance principle and provides continuous output. Temperature range is -40 to 150 °F. Wetted parts are 316 stainless steel and teflon. This sensor is operable for the expected FARV temperature requirements.

Sensors. The pressure, temperature, and level sensors utilized in the storage tank are similar to those used in the transfer system. All sensors and metering devices are fully compatible with LP and operable across the expected FARV temperature range.

LP Loading System

LP is expected to be received from the manufacturer in standard 30 gallon HAZMAT drums, and it is planned to upload the ARM II/LP system directly from these drums. To accomplish this, each drum is first altered by installing a polyethylene draw tube through the larger (2 in.) bunghole. Immediately prior to transferring LP, an adapter containing one half of a quick disconnect coupling is first threaded into the large bunghole, and a flexible hose containing the mating coupling half is then connected to it. Figure 14 shows the additions and modifications necessary for bulk upload and download operations. The opposite end of this hose remains permanently connected to the LP system HAZMAT port. To complete preparations, an acoustic level sensor is installed through the smaller (0.75 in.) bunghole.

HAZMAT Drums. The 30 gallon HAZMAT drums to be used for uploading or downloading the ARM II/LP system are standard, commercially available hazardous material shipping drums. These composite containers utilize a steel drum per DOT spec 6D and a polyethylene inner liner per DOT spec 2SL. To be able to extract LP from them, each drum is modified by removing the larger bunghole plug and installing a polyethylene draw tube and plug in its place. The draw tube also includes a sliding float that closes off the tube inlet when the drum is nearly empty so as to prevent air from being drawn into the system. Because these standard drums have flat bottoms, it is

impossible to extract all of the LP without ingesting some air, hence a small quantity of LP (approximately one to two gallons) will normally be left in them. To reduce this residual LP in the future, the drum liner bottom could be designed with a depression for the draw tube to project into and draw from.

HAZMAT Drum Level Sensor. An acoustic level sensor is used to monitor fluid level within a drum while it is being emptied or filled and signal the pump to stop and appropriate valves to close when near-full or near-empty conditions are reached. The level sensor is installed by first threading a plastic adapter into the smaller bung hole and then inserting the sensor into the adapter. This adapter also provides venting of the drum while LP is transferred. Electrical signals are transmitted between the sensor and the ARM II/LP electronics by a small cable routed along the flexible hose. Although the sensor will not normally contact LP, compatible materials will be utilized to protect against inadvertent exposure.

HAZMAT Drum Loading Hose. A 1.25 inch ID flexible hose approximately 20 feet in length is utilized for connecting HAZMAT drums to the ARM II/LP system HAZMAT port. When not in use, this hose is coiled and stowed within the LP system cabinet. The inboard end is permanently connected to the HAZMAT port and the outboard end contains the female half of a quick disconnect coupling. To connect to the HAZMAT drum, an adapter containing a male quick disconnect coupling half is first threaded into the larger bunghole after the drum plug is removed, and then the quick disconnects are coupled. The special quick disconnect couplings are designed for minimal spillage upon disconnection - 0.04 cc. maximum or about one drop.

Vehicle Interface

The mechanical interconnection between the ARM II/LP system and the Bradley MLRS carrier is accomplished by two major components, the vehicle interface structure and the pallet assembly (fig. 15). The vehicle interface structure consists of two identical 12-in. channels bolted into the well of the vehicle cargo area, each with four steel mounts projecting upward. The pallet assembly is a weldment of various structural aluminum shapes forming a rectangular structure seven inches thick. The upper side of the pallet provides mounting features for the projectile magazines and the LP system and electronics cabinet, additionally, the conveyor drive is mounted to the lower side. Slots in the pallet engage the eight steel mounts of the vehicle interface structure when the palletized system is lowered into position, and cross bolting at each mount secure the system in place.

Projectile Storage System

The projectile storage system consists of two projectile magazines that are independently mounted to the top of the pallet assembly in a side by side arrangement (fig. 16). Each magazine consists of a bucket carrier serpentine, a handoff unit, and a drive train. Since each magazine is independently driven and has its own handoff unit, one magazine is able to search for a desired projectile at high speed while the other is transferring a projectile to the conveyor. Most of the ARM II/Uni magazine design was retained for ARM II/LP and most parts are common - the fundamental difference is that the ARM II/Uni magazines are located end to end with a single handoff/selector unit between them, while the ARM II/LP magazines are side by side with each having a dedicated handoff unit.

Bucket Carriers

Each projectile serpentine consists of an endless chain of 32 bucket carriers,

each carrier fully restraining the round under normal operating conditions to eliminate friction with guide surfaces within the magazine. Because of the side by side magazine arrangement, the two serpentines are identical, whereas in the ARM II/Uni magazines the forward serpentine is opposite hand from the aft serpentine. At the handoff unit, projectiles are snapped into or out of the carriers.

Handoff Unit

The two identical ARM II/LP handoff units, one for each magazine, are similar to the single bi-directional ARM II/Uni handoff/selector unit except all parts associated with the forward magazine handoff have been deleted. Additionally, the two handoff unit side plates are redesigned and an end panel added to facilitate enclosing the forward end of each magazine.

Drive Assembly

The serpentines and handoff mechanisms of each projectile magazine are driven by an identical, independently operated drive system consisting of a motor, speed reducer and gear train. This portion of the projectile storage system is identical to the ARM II/Uni drive system.

Drive power is provided by a commonly used 28 volt DC electric motor, which can deliver 2.5 HP continuous at 5000 RPM with a 130 amp current draw. This maximum speed will be applied for short duration high speed search, with a commercially available speed reducer providing the necessary reduction to drive the serpentine at 80 rounds per minute. Most of the time the drive motor will operate at 1250 RPM, corresponding to 20 rounds per minute.

Conveyor System

The transfer conveyor system consists of four distinct interconnected conveyors (handoff, stub, extendible, and docking head) which together provide the means to transport projectiles between the ARM II/LP storage magazines and the future Howitzer, which is to be represented by a surrogate rearm port for ARM II/LP demonstration (fig. 19). A detaching load tray also enables the conveyor to upload and download between the ground or pallets, various trucks and other resupply vehicles, and the current M109 Howitzer. An equilibrator counteracts a significant portion of the cantilevered load to facilitate positioning by the operator during deployment. The transfer conveyor system is powered by its own drive assembly. LP is transferred between the ARM II/LP system and the surrogate rearm port (or future Howitzer) by means of a hose attached to the conveyor system with a special fluid coupling located in the conveyor docking head. When not in use, the conveyor is swung into its stow position along side the system, and the docking head is engaged with the stow receptacle. This receptacle restrains and supports the conveyor during transport, protects the docking head, and also provides a mating LP coupling that is plumbed to the LP pumping system for the purpose of LP recirculation and air purging.

Handoff Conveyor

The handoff conveyor has the longest fixed length of all of the conveyor segments and extends across the full width of the two side by side projectile magazines, passing through the handoff units of both magazines. Its function for download is to accept munitions from the magazines and transport them to the remainder of the conveyor system. During upload, the handoff conveyor carries projectiles into the magazines and positions them for controlled handoff into the selected serpentine.

Conveyor power is applied to the left end of the handoff conveyor via a roller chain driven by the drive assembly, and is then distributed to the remainder of the conveyor system by means of a gear mesh between the handoff and stub conveyors.

Stub Conveyor

Unlike the handoff conveyor which is mounted in a fixed position, the stub conveyor plus the remaining conveyor sections form the moveable docking arm which is stowed along the left side of the vehicle and is swung out 90 degrees to deploy. The stub conveyor assembly is the inboard end of the docking arm and contains all of the structural features needed to support the cantilevered load, as well as a short (28 inches long) projectile conveyor section. The 90 degree deployment action is accomplished by upper and lower hinges that interface with an upper bracket extending from the top of the left magazine and a lower bracket extending from the pallet assembly. The function of the stub conveyor during projectile transfer is to assure that projectiles are aligned with the magazine entrance as they enter, hence, this conveyor section is always latched in the 90 degree deployed position during operation. The left end of the stub conveyor contains the inboard gimbal which permits the remainder of the conveyor to articulate vertically and laterally.

Extendible Conveyor

This conveyor section attaches to the aforementioned stub conveyor inboard gimbal and is therefore free to articulate relative to the stub conveyor, additionally, this conveyor can telescope to vary the overall docking arm length. The extendible conveyor range of adjustment is summarized below.

- +/-5 degrees forward and aft relative to stub conveyor.

- +/-15 degrees up or down relative to stub conveyor.

- 40 in. extension range.

The extendible conveyor consists of two main components, the fixed section (inboard) and the telescoping section (outboard). V-grooved rollers riding on rails facilitate the length adjustment operation once the extension latch is released. The equilibrator attaches to the left end of the fixed section and to the top of the stub conveyor structure, thereby supporting the weight of the conveyor and controlling the vertical positioning.

Docking Head

The docking head is the outermost section of the docking arm and provides the necessary features for aligning and latching it to the rearm port of a vehicle to be resupplied. Within the docking head is a short conveyor, very similar to the stub conveyor, for transporting projectiles through it. The docking head connects to the extendible conveyor by means of the outboard gimbal, which provides vertical and lateral articulation identical to the inboard gimbal. The docking head also contains one half of the LP hose coupling, which can be adjusted rotationally to align with its mating half in the rearm port, and an electrical actuator for extending the coupling and engaging it with its mate. The docking head range of adjustment is summarized below.

- +/-5 degrees forward and aft relative to extendible conveyor.

- +/-15 degrees up or down relative to extendible conveyor.

- +/-10 degrees rotation of LP coupling about projectile centerline.

When the ARM II/LP system is to be engaged in auxiliary projectile transfer operations, that is, when the docking head is not directly connected to a mating rearm port but is instead interfacing with pallets, truck beds, or current Howitzers, fold down legs can be deployed to position the conveyor at a comfortable height, or the docking head can rest directly on any convenient surface. To assure a safe and reliable transfer of projectiles into or out of the docking head when in these modes, a detachable load tray is first mounted to the docking head. LP cannot be transferred through the docking head coupling when these auxiliary modes are in use.

Drive Assembly

The transfer conveyor system is powered by an autonomous drive assembly consisting of a 5.0 HP, 28 volt DC electric motor coupled to a commercially available gear reducer. An identical motor drives the LP pump. The reducer output drives the left end of the handoff conveyor through a roller chain, and also drives the conveyor position encoder. The conveyor drive assembly mounts to the underside of the pallet assembly, below the left magazine.

Equilibrator

The equilibrator assembly connects between the top of the stub conveyor structure and the extendible conveyor fixed section and provides the force necessary to counter the cantilevered load and thereby facilitate positioning of the docking arm. The equilibration force is supplied by a hydro-pneumatic system very similar to that employed by ARM II/Uni. A conventional hydraulic cylinder is located within the equilibrator strut assembly and the hydraulic oil outflow is connected by a flexible hose to an gas-charged accumulator located within the stub conveyor structure. Within this interconnecting flow path are three valves connected in parallel. One valve is a simple check valve that allows unrestricted flow if the docking arm is lifted. The second valve is an adjustable pressure relief, which is set just high enough so that the equilibrator will support the entire conveyor when extended but empty but will open and allow the conveyor to descend if any additional load is applied. The third valve is a manual valve, which the operator can open to bypass the other valves and allow the docking arm to descend when desired.

Load Tray

During projectile transfers in which the docking head is not connected to a rearm port, the detachable load tray is employed to facilitate the manual transfer of projectiles into or out of the docking head. This tray attaches to the face of the docking head and supports the weight of a projectile until it is either manually lifted off or slid into the docking head where it is picked up by the conveyor. While a projectile is in the tray, a switch within the docking head is automatically activated to prevent another projectile from exiting the docking head and colliding with the first. When not in use, the load tray is stowed in a compartment within the ARM II/LP system.

Stow Receptacle

The conveyor stow receptacle is located at the left rear corner of the ARM II/LP system and provides a port in which the docking head can engage when the conveyor is swung into its stow position. This receptacle mimics the rearm port but its purpose is to restrain and support the conveyor during transport, and protect the docking head. Additionally, the stow receptacle contains a mating LP coupling that is plumbed to

a return line to the LP storage tank. Whenever the conveyor is placed in its stow position, the docking head LP coupling will be extended to mate with the stow receptacle coupling. This protects the coupling faces from contamination and also enables low flow LP pumping for system checkout and air purging. The stow receptacle also houses the maintenance control panel, as this vantage point provides the operator with good views of the conveyor and the LP system.

Surrogate Rearm Port

The surrogate rearm port is intended to represent the potential rearm port configuration for the future Howitzer, and provides for the transfer of both LP and projectiles in a manner consistent with anticipated mechanization of the actual Howitzer. It is not physically a portion of the ARM II/LP system, but is needed for mating with the ARM II/LP system during demonstration, and is more appropriately categorized as test support equipment. In addition to the port itself, this equipment will include appropriate projectile handling and LP handling hardware, as well as an electrical control system.

The rearm port is a relatively simple fixture containing a large bore with an inside locating cone for centering the docking head, receptacles for the docking head latches, and a fixed position LP coupling, all mounted to an adjustable height stand. The surrogate port LP system consists of hose, valves, plumbing, sensors and a storage tank, with most components common with the ARM II/LP system. Projectiles that pass through the port will first be received by the surrogate conveyor, which is a duplicate of the docking head conveyor, and then deposited into the load tray attached to the end of the conveyor (this is the same load tray used for auxiliary transfer operations, however in those cases it is attached directly to the docking head). Once in the load tray, projectiles are manually removed and placed on adjacent tables for temporary storage. Collision avoidance sensors will prevent approaching projectiles from entering the tray until the previous projectile is removed.

A simple, 120 volt AC electrical control system is employed in the surrogate rearm port hardware. The surrogate conveyor is powered by a manually controlled variable speed reversible electric motor. Communications between the surrogate port and the ARM II/LP system are established by means of a jumper cable that connects the surrogate port electrical system with the connector on the docking head that is normally used for the remote handset. The remote handset is then connected directly into the surrogate electrical system and is used to operate the ARM II/LP system through the surrogate port. This is analogous to the receiving vehicle (future Howitzer) taking control of the resupply vehicle, which is the anticipated control hierarchy.

SYSTEM OPERATION

System Deployment

Vehicle Positioning

To transition the ARM II/LP system from transport mode to upload or download operational modes, the ARM II/LP vehicle must first be appropriately positioned in relation to the mating vehicle or munitions pallet. The most critical vehicle positioning is required when the docking arm is to be interfaced with a rearm port on another vehicle, as six degrees of freedom must be satisfied. Once positioned, the ARM II/LP vehicle is placed in neutral with the engine running and the brake set. If transfer operations are to begin immediately, system power can be turned ON at the crew station in the vehicle cab.

Conveyor Deployment

Although the ARM II/LP system is capable of interfacing with various vehicles, pallets and even the ground, its primary interface is with a rearm port. The following conveyor deployment procedure is applicable to that mode of operation. This procedure differs only slightly in auxiliary modes of operation - the load tray will be attached, the support legs may be deployed, and certain docking arm joints may be locked.

- Retract docking head LP coupling from stow receptacle coupling.

- Unlatch docking head and retract docking arm slightly to disengage from stow receptacle.

- Swing out 90 degrees and latch stub conveyor.

- Release articulation and extension locks and move docking head into alignment with rearm port.

- Extend docking arm until head is engaged in port and engage latches.

- Rotate LP coupling to align with rearm port coupling if LP transfer is planned.

- Extend LP coupling when LP transfer is ready to commence. Projectile and LP transfer operations may now commence if rearm port signals ready.

LP Transfer

The ARM II/LP liquid propellant storage and transfer system consists of a single 250 gallon storage tank, a variable speed centrifugal pump, and a plumbing network capable of multiple modes of operation. These various modes of operation enable the transfer of LP to and from a surrogate rearm port, and to and from 30 gallon HAZMAT supply drums. Additional modes are available for various maintenance functions and emergency response.

Pump operation is controlled by various sensor inputs depending upon the selected mode of operation. During downloading to the surrogate port or to HAZMAT drums, the pump is commanded to specific flow rates using the system flow meter output as feedback, as shown in figure 20. During upload from HAZMAT drums or the surrogate port, pump speed is governed by the pump inlet suction pressure as shown in figure 21. Maintenance modes that utilize the main pump have fixed pump speeds assigned, with speed control feedback provided by the built-in drive motor tachometer. Other system sensors, such as temperature and pressure at the pump outlet, can override the currently active feedback signal and assume control of the pump and stop it whenever an out-of-limit condition is detected.

Further details of the LP system operational modes, maintenance modes, and emergency responses are provided in the following paragraphs.

Operational Modes

The LP storage and transfer system design was driven by four specific modes of operation - downloading to the surrogate port and to HAZMAT drums, and uploading from HAZMAT drums and from the surrogate port.

Download to Surrogate Port. This is the most critical operational mode since the flow rate is highest, 50 to 60 gpm, and pump outlet pressure is likewise highest. Once the conveyor is deployed and the docking head is latched to the surrogate port, LP transfer can commence. It should be noted that in this operational mode, the remote handset is plugged into the surrogate port electrical system and the ARM II/LP system is operated through it. The following actions describe the crew procedure.

- Turn system power ON at the crew station in the vehicle cab.

- Press TAKE CONTROL key on remote handset attached to surrogate port to take control of surrogate port and ARM II/LP system.

- Select DOWN LOAD LP and TO REARM PORT from remote handset menus.

- Choose the quantity to be downloaded from menus displaying the onboard inventory.

- Press START key on remote handset to initiate valve positioning and pump operation.

Once these actions are performed, valves in the surrogate port and the ARM II/LP system will move into their correct positions, the docking head LP coupling will extend, and if all sensor inputs are within acceptable limits, pumping will commence. The pump will accelerate until the flow meter indicates a minimum of 55 gpm flow rate, which will be maintained until the requested quantity is delivered, or the ARM II/LP tank low level sensor is tripped, or the surrogate port tank high level sensor is tripped. After the pump stops, all valves will return to their normal positions.

Upload from Surrogate Port. This mode of operation is utilized to return LP from the surrogate port tank back to the ARM II/LP system, and is not expected to be a commonly used tactical mode although it will be used frequently during ARM II/LP testing. Maximizing flow rate is not important in this mode. The crew procedure in this case is as follows.

- Turn system power ON at the crew station in the vehicle cab.

- Press TAKE CONTROL key on remote handset attached to surrogate port to take control of surrogate port and ARM II/LP system.

- Select UP LOAD LP and FROM REARM PORT from remote handset menus.

- Choose the quantity to be uploaded from menus displaying the surrogate port tank inventory.

- Press START key on remote handset to initiate valve positioning and pump operation.

Again, once these actions are performed, valves in the surrogate port and the ARM II/LP system will move into their correct positions, the docking head LP coupling will extend, and if all sensor inputs are within acceptable limits, pumping will commence. In this case, however, the pump will accelerate until the pump inlet suction pressure reaches a prescribed value, which will then be maintained until the requested quantity is delivered, or the ARM II/LP tank high level sensor is tripped, or the surrogate port tank low level sensor is tripped. After the pump stops, all valves will again return to their normal positions.

Upload from HAZMAT Drum. The ARM II/LP system is uploaded with LP that is provided in modified 30 gallon HAZMAT drums (draw tube added). Approximately nine drums are required to completely upload an empty system. The crew procedure for drum hookup and LP transfer is as follows:

1. Remove both bunghole plugs from first drum to be emptied, install level sensor adapter in smaller bunghole and loading hose quick disconnect adapter in larger bunghole.

2. Extract HAZMAT drum loading hose from LP cabinet and connect quick disconnect to mating half on drum adapter.

3. Insert acoustic level sensor into appropriate adapter.

4. If ARM II/LP system is not already primed, perform initial priming procedure now. Otherwise, skip this step.

5. Turn system power ON at the crew station in the vehicle cab.

6. Press TAKE CONTROL key on remote handset attached to docking head to take control of ARM II/LP system.

7. Select UP LOAD LP and FROM HAZMAT DRUM from remote handset menus.

8. Choose the quantity to be uploaded from menus displaying the HAZMAT drum level status.

9. Select appropriate LP lot number from list displayed on remote handset.

10. Press START key on remote handset to initiate valve positioning and pump operation.

Once these actions are performed, the transfer of LP from HAZMAT drum to ARM II/LP is accomplished by automatically positioning the appropriate valves and operating the main pump at slow speed. Regulation of pump speed is accomplished by feedback of pump inlet suction pressure so that a maximum transfer rate can be achieved without fear of cavitation. When the level sensor indicates the drum is near empty, or the ARM II/LP tank high level sensor is tripped, the pump is shut down and the HAZMAT port valve is closed to prevent backflow. Additionally, in the event that the level sensor fails to trigger pump shutdown when the drum reaches near-empty, a sliding float over the draw tube within the drum will close off the bottom inlet to block air ingestion. In this case, the resultant increased suction at the pump inlet combined with a diminished flow rate will also signal the pump to stop and the HAZMAT port valve to close.

Uploading the ARM II/LP system will require as many as nine 30 gallon drums of LP. As each drum is emptied, the quick disconnect adapter, flexible hose and level sensor and adapter are transferred to a fresh drum. Changeover time can be shortened by use of a second set of adapters, which can be installed into the next drum while the previous drum is being emptied. After a new drum is connected, the last three steps of the above sequence are repeated to resume upload. After HAZMAT drum transfer operations are completed, the hose is coiled and stowed within the LP system cabinet along with the quick disconnect adapter and the level sensor and adapter. The hose remains connected to the HAZMAT port, and it is normally left primed with LP for the next usage unless it is manually drained or air has been sucked into the system.

Download to HAZMAT Drum. This mode of operation is utilized to empty the ARM II/LP system by returning LP to HAZMAT drums, and is not expected to be a commonly used tactical mode although it will be used frequently during ARM II/LP testing. Maximizing flow rate is not important in this mode, although a flow rate of approximately 15 gpm is expected. The crew procedure in this case is as follows:

- Remove both bunghole plugs from first drum to be filled, install level sensor adapter in smaller bunghole and loading hose quick disconnect adapter in larger bunghole.

- Extract HAZMAT drum loading hose from LP cabinet and connect quick disconnect to mating half on drum adapter.

- Insert acoustic level sensor into appropriate adapter.

- Turn system power ON at the crew station in the vehicle cab.

- Press TAKE CONTROL key on remote handset attached to docking head to take control of ARM II/LP system.

- Select DOWN LOAD LP and TO HAZMAT DRUM from remote handset menus.

- Choose the quantity to be downloaded from menus displaying the onboard inventory.

- Press START key on remote handset to initiate valve positioning and pump operation.

Once these actions are performed, the transfer of LP from ARM II/LP to HAZMAT drums is accomplished by automatically positioning the appropriate valves and operating the main pump at slow speed. In this case pumping speed is regulated by the actual LP flow rate as determined by the system flow meter. As a HAZMAT drum fills, the fluid level is monitored by the acoustic level sensor. The pump is automatically stopped and the HAZMAT port valve closed when the drum reaches full, or the ARM II/LP tank low level sensor is tripped. The loading hardware is then transferred to an empty drum to continue downloading.

Maintenance Modes

The various LP system maintenance modes are defined as follows:

System Air Purging. This is accomplished by means of fluid recirculation through the conveyor hose and back to the storage tank and is initiated by the remote handset. To operate this mode, the docking head must be latched to the stow receptacle and the LP coupling extended to engage the recirculation coupling. Once the valves are positioned as required, the pump is run for approximately five minutes at a low rate to accomplish complete air purging.

Main Pump Initial Priming. An auxiliary priming pump (peristaltic pump) is utilized for this mode. After connecting the flexible loading hose to a HAZMAT drum per the "Upload from HAZMAT Drum" procedure, the priming sequence is initiated from the maintenance panel. This action positions the appropriate valves and starts the priming pump. The priming pump is manually held on until the level sensor in the main pump indicates the presence of fluid. The flow rate for the priming pump is approximately 0.6 gpm.

System Drain. This mode is the same as downloading to HAZMAT drums until the tank low level sensor inhibits pumping. The drain hose is then connected to a HAZMAT drum and the motorized valves are driven to the venting position. The manual valves are then held open until all LP, including fluid in the pump, is drained.

System Water Purge. De-ionized water stored in modified 30 gallon HAZMAT drums is used in this mode. The operation is similar to LP upload from HAZMAT drums except water is loaded rather than LP. After 250 gallons of water are uploaded from the drums; the recirculation mode (system air purging) is operated until three purge cycles are completed. The water is then downloaded to the drums, and the remaining water is manually drained from the system.

Emergency Procedures

There are two levels of emergency, level 1 emergency which triggers an alarm to alert the operators and level 2 emergency which aborts the current operation and initiates an automatic LP dump to a controlled external tank. For power off monitoring, selected sensors and an alarm are kept active by direct powering from the vehicle batteries.

A level 1 emergency condition exists whenever a temperature or a pressure sensor within the system exceeds a preset threshold level; or the smoke detector signals the presence of smoke. The response will consist of an audible alarm followed by pump shutdown and motorized valve positioning to allow complete system venting to the storage tank. Monitoring of sensors for fuming condition evidence will continue until it can be determined that either the emergency no longer exists or that an emergency LP dump is necessary. If the emergency condition was a false alarm, then the audible alarm is disabled. The emergency LP dump will occur automatically if conditions progress to a level 2 emergency.

A level 2 emergency condition exists when any two temperature sensors within the storage tank exceed the preset temperature, and the smoke detector indicates the presence of smoke. This set of conditions indicates a strong likelihood of an incipient fume-off reaction taking place within the storage tank. The response in this case will be to sound a higher pitch alarm and initiate an automatic LP dump.

The automatic dump is intended to dilute and cool down the reacting LP. When the automatic LP dump is initiated, the dump valve is opened which allows rapid draining of the fluid into an external tank partially filled with water. At the same time, an auxiliary pump will start re-circulating the cool water back to the storage tank in the vehicle. The external reservoir will contain enough cool water to dilute the LP to a safe level.

During periods in which the loaded vehicle is unattended, the smoke detector and a temperature sensor in the storage tank will be powered by the vehicle batteries. In the event that either of these sensors detect an abnormal condition, an audible alarm will be sounded and a flashing red light will be activated. There will not be an automatic LP dump during this condition.

Projectile Transfer

Upload

Routine upload of projectiles will not normally involve a rearm port since projectiles are usually uploaded from pallets on the ground or a truck bed. Thus, most

upload operations will be performed with the load tray attached directly to the docking head. For this most common upload mode, the crew procedure consists of performing the following actions:

- Turn system power ON at the crew station in the vehicle cab.

- Press TAKE CONTROL key on remote handset to take control of system.

- Select UP LOAD PROJECTILES and PROJECTILE AUTO READ from the remote handset menus.

- Press START key on remote handset to initiate conveyor motion.

- Place projectiles nose first onto load tray and slide forward until picked up by the docking head conveyor. Continue until all projectiles are loaded or all spaces in projectile magazines are filled.

Once the above actions are performed, the system controls will coordinate conveyor and magazine motion automatically. System logic will determine which of the two magazines and which of the 32 carriers in each magazine each projectile is destined, based upon minimizing upload time while distributing the projectile mass relatively evenly. As each projectile enters the left magazine handoff unit, the fuse and projectile labels are each scanned in sequence as they pass their respective munition ID cameras. The projectile then either stops for the left magazine or continues into the right magazine, as determined by the logic. Whenever a projectile approaches its handoff position, the entire conveyor quickly decelerates and stops, then restarts after the handoff is complete. If a projectile or fuse label cannot be read, the conveyor stops and the operator is given the choice of entering the identification manually or restarting the conveyor and placing the unidentified projectile into a magazine for later removal and identification.

Download

Routine download of projectiles from the ARM II/LP system will normally involve the docking head being latched to the surrogate rearm port. In this case, projectiles pass through the port and onto the surrogate conveyor before being deposited into the load tray where they must be removed manually. The crew procedure for this download mode consists of performing the following actions:

- Turn system power ON at the crew station in the vehicle cab.

- Press TAKE CONTROL key on remote handset attached to surrogate port to take control of surrogate port and ARM II/LP system.

- Select DOWN LOAD PROJECTILES from the remote handset menus.

- Choose the types and quantities of items to be downloaded from menus displaying the onboard inventory.

- Press START key on remote handset to initiate magazine and conveyor motion.

- Manually remove projectiles as they arrive at the load tray.

Once the above actions are performed, the system controls will again

coordinate conveyor and magazine motion automatically. System logic will determine the order that chosen items are delivered based upon minimizing download time.

Auxiliary and Maintenance Functions

The following auxiliary functions are available to aid in operation and maintenance of the projectile handling systems and to provide for degraded modes of operation.

Manual Control. The projectile magazines and transfer conveyor can be controlled manually by using the maintenance control panel. This may be initiated to perform maintenance functions or to download the system in the event of computer failure, as examples.

Built-in Test. Built-in test (BIT) functions are included in the system software to test the functions of its processor and its interfaces. One of the handset maintenance menus will display the results of these tests.

System Status. The status of all system sensors and actuators can be displayed by selecting another of the maintenance menus. This is used for maintenance and system alignment. Also displayed with this menu is system usage data such as total hours of operation, total number of projectiles transferred and total quantity of LP transferred.

Lot Number Cross Reference. A cross reference menu will be used to assign single letter lot identifiers to the actual projectile lot numbers. All other operator menus will identify lots by the single letter identifier.

LP STUDY

At program onset, an in-depth study of LP was undertaken to gain a complete as possible understanding of this new and unique substance. This knowledge was considered a prerequisite to the successful formulation of a LP resupply concept. The results of this study are compiled in a non-published document patterned after the JPL Liquid Propellant 1846 Handbook, which was prepared by NASA's Jet Propulsion Laboratory (JPL). This document will not be published as it is not a stand alone document, however the following paragraphs provide an overview of the LP study. Information gathering for the Phase I LP study consisted primarily of literature searches, visits to knowledgeable individuals and organizations, and subcontracted consultation - all of which was focussed on collecting currently known data pertinent to the field artillery resupply mission. Basic LP characteristics such as physical, chemical, thermodynamic and transport properties were sought out and compiled, as were environmental, safety, and regulatory considerations pertaining to the storage, handling, transportation and disposal of LP.

In addition to searching out all known information about LP, the LP study was also tasked with identifying apparently conflicting data as well as yet unknown characteristics of LP. Because of the short duration of Phase I, it was not the intent of the LP study to rectify all conflicts and unknowns, only identify them. The Phase II LP study continuation will address such issues that are pertinent to the evolving ARM II/LP concept and resolve them as thoroughly as possible. This will be accomplished primarily through bench testing and experimentation, and several candidate investigations have already been outlined.

As the Phase I LP study progressed it became apparent that, although some gaps do

exist, an extensive data base of LP knowledge is already in place throughout government and industry, and that seriously conflicting data is rare. It also became obvious through the LP study that LGP 1846 is not a mysterious, unpredictable substance to be feared, but it is a hazardous and explosive material that must always be treated with appropriate respect. LP handling mechanization, however it may be implemented, need only adhere unfailingly to this simple guideline to be totally safe and effective.

Government/Contractor Agencies Visited

The first organization visited was the Army Research Laboratory (ARL), formerly the Ballistics Research Laboratory (BRL), at Aberdeen Proving Ground, Maryland. The individuals contacted were Nathan Klein, Bob Frey, and Jerry Watson. The discussion with Nathan Klein focussed on LP physical and chemical properties as well as decomposition and reaction mechanisms. The meeting with Bob Frey and Jerry Watson addressed vulnerability issues.

The Army Research, Development, and Engineering Center (ARDEC) at Picatinny Arsenal, New Jersey was visited next. The people contacted were: Jim Rutkowski, Janet Gardner, Peter Bonnett, Richard Kopmann, James Zoll, Frank Chan, Nora DeVries, Chris Goll, Wayne Miller, Bapu Laksaminarayan, Carl Morrison, Mike Selk, and Tony Beardell. The main discussion topics were LP pumping, logistics, shipping containers, safety, and LP disposal.

The Second LP Transfer System Workshop, held at ARDEC, was also attended. This provided an excellent opportunity for exposing some of the ARM II/LP team to the LP community and to get an update on the current issues and ongoing projects related to LP. In addition to the formal presentations, several informal side discussions were held with attending LP experts such as Ned Ferraro, Cliff Moran, and Darrel Jan from JPL; Don Swenson from MM Defense Systems; Jimmie Oxley and Douglas Olson from NMIMT; Jerry Watson from ARL; and Janet Gardner from ARDEC.

Thiokol Corporation, at Elkton, Maryland, was visited next. Discussions with Dan Goggins, Warren Graser, and Rod Miller focused on the LP manufacturing process, safety issues, instrumentation, and potential test support for the ARM II/LP program.

Olin Corporation at Charleston, Tennessee was also visited. Among those contacted were Robert Brooker, Sanders Moore, Ronald Dotson, and William Kurtz. Peter Bonnett and Chris Goll from ARDEC were also present. The main discussions centered around Olin's experience pumping LGP 1846 and hydroxylammonium nitrate (HAN), one of the main constituents of LGP 1846, by means of an air operated diaphragm pump and a magnetically coupled centrifugal pump, respectively. Discussions also included abnormal experiences while pumping HAN, LP quality monitoring, and LP manufacturing.

The Martin Marietta LP pumping test site at Malta, New York was visited next. A meeting was held with Don Swenson from Martin Marietta Defense Systems and Sudhir Savkar from GE CR&D, which included discussions on LP decomposition theory; pump trade offs; their LP pumping system test setup and instrumentation; and potential test support for the ARM II/LP program.

Applied Ordnance Technology (AOT) at Sparta, New Jersey was also visited. The individuals contacted were Barry Ward, Bill Hermann, and Maureen Moran. The topics discussed were: hazard analysis support, disposal regulations and procedures, personnel training, and operating procedures. AOT was subsequently subcontracted to provide support in the area of safety and environmental regulations.

Subcontracts

Martin Marietta sought outside consultation support from several experts to accelerate the acclimation process with regard to LP pumping systems, hardware compatibility, and environmental and safety issues.

Due to their vast experience with LP guns and high flow LP transfer, Martin Marietta Defense Systems and GE CR&D were subcontracted to support the ARM II/LP pumping analysis and hardware selection. Their contributions included participation in a concept review held at Malta, New York, and consultation on the pumping system design, and compatibility of materials.

Applied Ordnance Technology was subcontracted to provide support on the environmental and safety issues related to handling LP. AOT provided past AOT LP related publications, and developed and presented an LP environmental/safety briefing at Burlington for the design team.

Schreib Engineering was subcontracted for consultation on the ARM II/LP flow resistance analysis. Assistance was also provided in the pumping hardware trade-off and selection process.

Unknown LP Characteristics

Although present knowledge of LGP 1846 is extensive, the LP study and ARM II/LP system conception did raise a few questions that currently have no absolute answers. Since these issues have some bearing on the ARM II/LP mechanism design and the program in general, more definitive answers must eventually be found. A brief description of the more significant issues follows:

- In the event that a very localized LP decomposition reaction initiates within a large volume of LP, perhaps triggered by the tip of a pump impeller, for example, the parameters that determine the outcome are unknown. Perhaps heat transfer into the surrounding LP will extinguish the reaction, perhaps it will propagate throughout the remaining volume.

- Reliable detection of an incipient LP decomposition reaction is necessary if an emergency response system is to be fail-safe. A smoke detector within the LP storage tank is under consideration for this purpose, but no data currently exists that proves this approach will reliably and rapidly signal the presence of decomposition gases.

- A LP/water dilution threshold, below which the mixture can oe safely handled and is no longer classified as an explosive, must be established to facilitate LP shipment and disposal.

- The establishment of LP/water dilution thresholds, below which the mixture can be disposed of in a municipal sewage system or on the open ground, would greatly facilitate LP disposal.

- Extensive parametric testing is needed to define an operational envelope that, if kept within, provides an absolutely benign environment in which a runaway decomposition reaction cannot occur.

Phase II LP Study Continuation Tests

In Phase II of the ARM II/LP program, the LP study will continue, however, it will not entail updates to the non-published document, as determined by the government. It is understood that the Liquid Propellent 1846 Handbook[2] is being extensively revised (due April/May 1994), and any new information that are pertinent to the evolving ARM II/LP concept will be addressed and resolved as thoroughly as possible. Primary emphasis will be on bench tests and experiments that address potential concerns and fill in missing data relative to the ARM II/LP design and the performance of selected hardware. The primary objective is risk mitigation through concept verification by test. Some of the experiments under consideration are discussed below.

Centrifugal Pump Characterization Test

The objective of this test is to evaluate the sensitivity of LP to unintentional ignition when subjected to pumping. The test will be conducted under maximum operating conditions as well as over capacity conditions (25% over maximum flow rate). The test will be conducted with a centrifugal pump similar to the chosen model.

This test will consist of a closed loop pumping setup as shown in Figure 22. It will include a small reservoir; a flow meter; throttle valves to regulate the discharge and intake flow; and a fast acting valve to induce water hammer. Pressure and temperature will be monitored at the inlet and outlet of the pump; an acoustic sensor will also be used to detect cavitation. The pump operational range will be investigated under extreme conditions.

Additionally, the entire dynamic range of the pump will be characterized using water as the working fluid, and then repeated using an LP stimulant. Temperature, pressure and flow will be recorded throughout the testing. This information will establish a baseline for actual LP testing.

Flexible Hose and Quick Disconnects

A functional test will be conducted by means of a conveyor mock-up. The suitability of the selected flexible hose for use in the extendible conveyor will be assessed. The quick disconnects will also be tested under fluid transfer conditions by repeated engagements and disengagements. Their susceptibility to leaks as well as ease of operation will be evaluated in this manner.

System Simulation/Breadboard Test

The system simulation will be a full scale test prior to the release of the design. It will serve as a means to verify the line loss analysis by measuring pressure drop across the system in all operational modes. The valve operation in all modes will also be verified. The lift capability from the HAZMAT drums will be characterized in terms of flow rate as a function of drum height.

LP SYSTEM ANALYSIS AND TRADE STUDIES

Flow analysis of the LP transfer system was conducted to size the transfer piping and the pump and to quantify system performance. The approach taken was to over-design the pump to obtain smaller pressure heads and lower pump impeller speeds. The hydraulic analysis was performed with the aid of a commercially available software package. The main parameter affecting the line and pump sizing was the flow rate requirement (50 gpm) for download to the surrogate port. Cavitation was the controlling

parameter when analyzing the upload from HAZMAT drums.

The worst case for the pipe sizing analysis, in terms of flow resistance, occurs at the lowest operational temperature. The low temperature operational requirement for ARM II/LP is 32°F; however, the analysis also included the effects of a -40°F operating environment. Conversely, the highest temperature environment was important when analyzing suction limitations due to cavitation.

Piping and Pump Size Analysis

The line size analysis was conducted for a maximum flow rate of 55 gpm, which restricted the pipe diameter to 1.25 in. and above. The system was first modeled and analyzed for 1.5 in. piping, and a scaling method was then used to determine the pressure for 1.25 in. and 1.0 in. pipe diameters. Figure 23 shows a plot of pressure drop versus flow rate when downloading to the surrogate port at 30°F. From this plot it can be seen that for 55 gpm, 1.5 in. and 1.25 in. pipe diameters are acceptable in terms of pressure drop; 40 psi and 72 psi, respectively.

The centrifugal pump was then sized for the download to the surrogate port mode. The pump performance curves were scrutinized to select the operating point. A family of performance curves for different pump speeds is shown in figure 24. This figure shows pump speeds up to 1750 rpm; higher pump speeds were not desired. Since the conditions for 1.25 in. diameter piping required higher pump speeds, 1.5 in diameter piping was selected. From figure 24 it is observed that for 55 gpm and about 40 psi pressure drop, a pump speed of 1500 rpm is required. The efficiency of this operating point is approximately 30%.

The other important mode to consider was the upload of LP from HAZMAT drums. The driving parameter in this case was cavitation. A resupply time of 30 minutes is allowed in this mode. A line size analysis was also performed with 1.5, 1.25, and 1.0 in. diameter hoses and fittings. Shown in figure 25 is a plot of net positive suction head available (NPSHa) as a function of flow rate for the different pipe sizes and two different temperatures.

The net positive suction head required (NPSHr) by the pump is also displayed in the plot. To avoid cavitation, the NPSHa has to be greater than the NPSHr. Thus, anything above the NPSHr line in figure 25 will be acceptable; however, a design limit was imposed to allow a safety factor of two. Therefore, a 1.25 in. line size was selected for the piping and hose used for interfacing with the HAZMAT drums. The 1.0 in. size was marginally acceptable but was rejected to minimize risk.

An assessment of the required line size for gravity feed emergency dumping of LP was also conducted. A flow rate of at least 50 - 100 gpm was desired for this function. Three pipe sizes were analyzed for flow resistance: 2.0, 2.5, and 3.0 in. Figure 26 displays a plot of flow rate versus tank level for the three line sizes. A 3.0 in. diameter pipe was selected to be conservative.

Pressure Drop Analysis for Temperature Extremes

A piece-wise pressure drop analysis across important components and nodes was also conducted. This analysis established the pump performance needed to achieve the desired flow rate under various operating temperatures, which was then used to determine the corresponding pump operating speeds. The three temperatures considered were 125°, 30°, and -40°F. Diagrams of the transfer system and node locations, as well as a pressure map for the different temperatures at the desired flows were developed.

Figure 27 shows the flow path utilized for downloading to the surrogate port, and the corresponding pressure map. From this figure it is observed that at 30°F, differential pressure (discharge minus suction) of 40 psig is required which, for the baseline pump requires a speed of 1500 rpm. The conditions for 125°F are more benign than those at 30°F. A differential pressure of about 58 psig is required when pumping at -40°F with a pump speed of 1850 rpm. Thus, it is possible to download LP to the surrogate port under this condition, although low temperature testing of ARM II/LP will be limited to 32°F.

The flow path for uploading from HAZMAT drums is depicted in figure 28. The pressure map shows that for a flow of 20 gpm at 30°F and 550 rpm, a differential pressure of 5 psig is needed, most of which is required for suction. The conditions for 125°F are similar. For -40°F, the required differential pressure is 10 psig at 750 rpm and 13 gpm. This flow rate is still able to satisfy the upload time requirements. The suction pressure is about -9 psig which is the imposed design limit. This indicates that uploading from HAZMAT drums at -40°F appears to be feasible, but further evaluation is recommended.

Figure 29 show the path required to upload from the surrogate port and the corresponding pressure maps. Upload from the surrogate port at 30° and 125°F is achieved at 500 rpm with flow rates of 21 and 22 gpm, respectively. When uploading at -40°F, the maximum obtainable flow rate is 14 gpm to stay above the -9 psig suction pressure limit. This requires a pump speed of about 750 rpm.

Figure 30 depicts the path and pressure map for downloading into HAZMAT drums. The pressure maps indicate that pumping to the HAZMAT drums is easily achieved for all of the required temperatures. A discharge pressure of 10 psig, and a suction of less than -2 psig is required for the worst case (-40°F).

Trade Studies

The trade studies were conducted jointly by systems and mechanical engineers to obtain multiple viewpoints on the many LP storage and transfer options. In many cases missing information on LP behavior made it difficult to fully evaluate some of the options. The final solutions from the trade studies were made in favor of maximum safety and minimum risk.

Transfer Methods

The transfer methods considered and traded off were: pumping, pressurized storage tank, and pressurized bladder. The pumping method was selected mainly because of the lower operational pressure, no need for a pressure vessel, and overall safety. Table 1 shows the transfer method trade study.

Storage Systems

The storage system selected consists of a single storage tank which offers the most efficient packaging; simplest mechanization; and a minimum number of sensors, valves, and fittings. The single tank concept also features better reliability, accessibility, and maintainability due to simplicity. The technical risk associated with this concept is low. The chosen concept was traded off against dual manifolded tanks, dual tanks with a pump in between, HAZMAT drums in series and in parallel, and a pressurized bladder. A trade study of the storage tank configuration is shown in Table 2.

Pumps

Since the main component in the transfer system is the pump, a trade study was conducted to select the most appropriate pump technology. Table 3 shows the pump trade study. The pumps considered were: hydraulic drive diaphragm, mechanical seal centrifugal, magnetic drive centrifugal, canned motor centrifugal, flexible impeller, bi-rotor lobe, peristaltic, rotary gear with mechanical seals, and magnetic drive rotary gear.

Based on this trade-off, the recommended concept is a centrifugal pump, and the baseline choice is a self-priming model with stainless steel wetted parts and mechanical shaft seals. The selection was based on lower risk of adiabatic compression as compared to positive displacement pumps; ability to operate dry; and temperature compatibility with ARM II/LP as well as FARV requirements. Cost, weight, and size are on the lower end; technology is off-the-shelf.

A disadvantage of this baseline pump is the mechanical shaft seals, which create the potential for leaks and shear heating. However, the technical risk associated with this is minimal. The magnetically driven centrifugal pump approach would also eliminate the seal problem, and may be reconsidered in the detail design phase.

HUMAN ENGINEERING AND SYSTEM SAFETY

Introduction

This section summarizes the activities and results of the Human Engineering (HE) and System Safety (SS) Programs for the ARM II/LP Phase I Program. Included are the results of crew task analyses of normal/abnormal operating modes and the results of a Preliminary Hazard Analysis (also submitted as CDRL No. A008).

As noted in the SS Program Plan, the scope of this effort is tailored to reflect the proof-of-principle nature of this program. As a result, some SS and HE issues identified in the course of these programs may not be resolved in a manner commensurate with that of an objective system, but will be handled in the context of a technology demonstration program. The impact of this proof-of-principle tailoring may be that potential issues are resolved through operator procedures training and/or product CAUTION/WARNING labels in lieu of an inherent design feature or device which would be incorporated in an objective system.

While technology demonstration is the primary purpose of this program, Martin Marietta Armament Systems (MMAS) recognizes that the delivered hardware may be operated in quasi-operational environments by possibly less-than-optimally-trained personnel. MMAS will attempt to address these potential conditions through robust system/hardware design and specific attention to crew interface design. However, the following caveats should be noted:

- Current program budget and schedule constraints may result in user-interface features that are not of the same durability/compatibility with field conditions as those designed for an objective system

- Within the scope of this program there is no intent by MMAS to Man-rate this system, however the intent is to provide equipment that could be man-rated. Consequently, in order to minimize risk, conservative personnel safety and environmental protocols will be observed and

recommended in the use, handling and storage of the LP fluid as well as any diluted or otherwise contaminated by-products.

Background

The LP variant of the ARM programs represents a follow-on to the ARM I and ARM II/Uni programs. Because of the evolutionary nature and hardware commonality within these programs, the scope of the HE and SS programs of the current LP program is limited to LP-unique and new hardware issues. For example, the Remote Handset and projectile magazines for ARM II/Uni have been carried over to ARM II/LP with only minor changes to accommodate the use of LP in place of solid unicharge increments. Consequently, only the new configuration aspects of the magazines and the LP-menu options/data will be addressed since the functional operations of these system components have already been evaluated under the ARM II/Uni effort.

Human Engineering Analysis

In support of the preliminary design effort, HE performed a task analysis of each of the following system operating modes:

- Conveyor deployment (stowage)
- LP upload from HAZMAT drums
- LP download to HAZMAT drums
- Abnormal (LP temp/pressure) operation

Purpose

The purpose of these analyses was to look at certain system operating modes and to identify crew task requirements and necessary system/component capabilities. Due to the early program time frame, the analyses were based on only a conceptual definition of system hardware. Results of this activity were applied to defining system/component requirements and as a check on crew operability.

Task Analysis Results

For each of the operating modes cited above, a task analysis worksheet was completed. These worksheets, presented in Table 4, include the following evaluation categories: Action Performed, Hardware Interface, Feedback Received, Identified HFE/Safety/Environmental Issues and Miscellaneous Comments.

System Safety Analysis

During Phase I, System Safety Program activity included the conduct and documentation of a Preliminary Hazard Analysis (PHA, submitted as CDRL No. A008) and concurrent System Safety support of the preliminary design process. This report segment will summarize the results of these activities also presented at the Preliminary Design Review.

Purpose

The purpose of the PHA was to: identify potential safety hazards (to hardware and personnel), recommend appropriate solutions for control or elimination of the hazard, and to communicate these issues to engineering for consideration during preliminary system and hardware design. As noted earlier, the proof-of-principle nature of this program may limit the degree to which identified issues are resolved through

inherent design features. Since the immediate intent is technology demonstration and not a fielded system, resolution of certain identified issues may be through crew training procedures and/or CAUTION/WARNING labels located on the hardware.

PHA Results

Initially, the PHA process started with the development of a hazard fault tree (fig. 31) which was created to organize potential hazards by physical category. These categories included:

- Fume-off, Fire, Explosion
- Acoustic noise
- Electrical Shock
- Mechanical (hardware damage/personnel injury)
- Chemical Contact (ingestion, inhalation, eye/skin contact)
- Environmental Spill/Contamination

Within each category, potential failure modes and fault conditions were hypothesized based on the conceptual hardware definition and likely locations/components of occurrence. The remaining PHA effort used this list of candidate faults/failures as a baseline for further hazard analysis.

Documentation of the PHA was based on the guidelines of DI-SAFT-80101 and MIL-STD-882, Task 202. Entries to the Hazard Analysis Worksheets were made in the following categories: Hazard No. and Description, MIL-STD-882 Severity/Frequency rating (Risk Assessment Code), Recommended Hardware/Software change or CAUTION/WARNING label, and Other Comments. These worksheets, presented as Table 5, are organized by the primary sub-systems that make up the ARM II/LP system, i.e., Conveyor, LP Storage/Handling, Electronic Control and Projectile Magazine. The PHA process considered the potential hazards listed in the fault tree in the context of system operating modes and the corresponding crew tasks.

Summary of HE/SS Recommendations

The following list of recommended system/component design features for ARM II/LP have been generated from results of the HFE and System Safety Programs. As noted in earlier discussion, the scope of these programs and the resulting recommendations are limited to new configuration and LP-specific issues. Carry-over components such as the Projectile Magazines and the Remote Handset will not be included because their issues have been identified, discussed and resolved in previous ARM programs.

General

During all LP pumping operations, personnel will be remotely located away from active pumping interface areas, e.g., HAZMAT drums or docking head/mating port.

Hardware design should incorporate features to protect Operator/ Maintainer from moving hardware/pinch points, electrical shock and exposure to hazardous chemical, radiation, vibration and acoustic noise.

Active components such as pumps and valves should have fail-safe design features.

The system should be operable by MOS 13B with minimal additional training.

No more than two personnel are required to operate the system.

Goal: System to be operable by male/female 5th to 95th percentile soldier.

Conveyor

Conveyor tongue weight (at any extension) should not exceed lifting requirement of 13B (100 lbs.).

Mechanical/Electrical indication of LP coupling engagement to be indicated at/near docking head-to-mating port interface.

LP Handling/Storage

System to include an LP containment basin to collect and contain total system capacity (250+ gals) of any spilled, leaked, or otherwise discharged LP fluid.

Locally available or system contained (objective system) water source and emergency personnel shower/eye-wash plus first aid kit (with methylene-blue antidote) for treatment of personnel exposure.

Shields, barriers and/or protective locations for LP-carrying conduits and components to minimize potential for personnel exposure in the event of spills, ruptures or other LP discharges.

All materials normally in contact with LP to be in accordance with documented LP materials compatibility list.

Acoustic attenuation of LP pump/motor noise (as necessary) for compatibility with MIL-STD-1474 (unprotected ear) levels.

All LP carrying/storage components to have pressure relief features for both powered and unpowered conditions.

Pipe/valve configuration to allow all lines to be vented to the main tank for unpowered/unattended situations.

LP pump output to be design limited to allow maximum achievable pressure on the order of 100 psi.

Electronic Control

LP pressure and temperature to be monitored in all closed pipe sections.

Sensors, BIT, Diagnostics to monitor fluid temperature and pressure and to detect and communicate out of tolerance conditions. These conditions to be communicated to crew via an audio alarm and Remote Handset indications.

Valve status to be continuously monitored, based on actual position feedback as opposed to commanded position.

LP pumping to be limited to a flow rate of 20 GPM for upload/download to HAZMAT drums.

Phase II HE/SS Issues

Vehicle Alignment for Docking

During Phase I, requirements were developed to define the necessary inter-vehicle relationships for conveyor docking. These relationships were analytically defined, based on the proposed extension and articulation capabilities of the conveyor and docking head design and are summarized as follows:

- Separation distance - 180 +/-16 in.
- Lateral misalignment (GOAL) - +/-8 in. and +/-5 degree yaw angle
- Height misalignment (GOAL) - +/-12 in. and +/-15 degrees roll angle
- Pitch misalignment - +/-10 degrees relative pitch angle

However, what remains to be determined is the precision with which the ARM II/LP vehicle operator can position the host vehicle relative to the receiving platform to satisfy these requirements. The current assumption is that driver experience and eye-ball judgments will be sufficient to achieve the necessary vehicle alignment. If this approach proves to be inadequate, some mechanism such as alignment marks, sighting reticles or relative vehicle features will have to be developed to assist the driver in achieving a proper docking position. Without some indication of proper vehicle positioning before docking, two conditions could result:

1. Considerable effort might be exerted by the ground crew to achieve docking when, in fact, no solution is physically possible for the given vehicle position.

2. Trial-and-error type fine adjustment of vehicle position/orientation will be required with the conveyor deployed and subject to damage from mating vehicle contact.

Given the technology demonstration scope of the program, a complete solution to this problem for all field terrain conditions will not be undertaken at this time. However, this issue will need to be addressed for future system development efforts with either manual or tele-operated conveyor designs.

Docking Head Handles/Controls

The relative precision of the docking head to mating port alignment compared to that of the ARM II/Uni system may dictate some unique design requirements for manual lifting/positioning/locking handles for the conveyor and docking head.

The predecessor ARM II/Uni conveyor interfaced directly with the rear door of the M109 Howitzer, which has an opening of about 2 x 3 feet. The interfacing process was further simplified in that the conveyor/load tray could be grossly positioned to the exterior of the door (by ground personnel), then extended through the opening by interior Howitzer personnel. Additional azimuth, elevation and extension fine tuning could be accomplished at any time by the Howitzer crew.

The ARM II/LP docking interface will require considerably more precision on the part of the ground personnel and will also include additional azimuth and elevation degrees of freedom (for the docking head) plus a rotational adjustment for alignment of the LP coupling. Also, because the docking head will be rigidly secured to the mating port, some flexibility will have to be incorporated into the remaining conveyor/docking head joints to allow relative vehicle movement as the load is transferred from one vehicle to the other. These intermediate conveyor joints will need to be fixed for certain conveyor articulations and free to move for others. Thus manual controls will be needed

to permit quick and easy locking/unlocking of the two azimuth, two elevation and extension degrees-of-freedom for the conveyor/docking head plus rotational adjustment of the LP coupling position.

In addition to the required precision dictated by the ARM II/LP docking process, the added complexity of the docking head will likely increase the weight/resistance of the extendible portion of the conveyor (compared to that of ARM II/Uni). For operations where the mating port is above the nominal (horizontal) height of the conveyor, this additional weight may increase the difficulty of extending the conveyor. This may require special handles, for both pushing (from the ground) or pulling (while standing on a higher truck platform). This additional weight plus the corresponding increase in sliding friction may limit the crew's ability to extend the conveyor at extreme elevation angles.

HAZMAT Operations

For the purposes of this program, all LP pumping to and from HAZMAT drums will observe conservative safety protocols. These will include requiring personnel to be remotely located from the drums during pumping and that pumping is initiated and controlled via the Remote Handset. With a HAZMAT pumping rate of up to 20 gal/min, eight to nine drum connections-reconnections and the remote crew location protocols the (self-imposed) goal of uploading from HAZMAT drums in 30 min may not be achievable. However, since the ARM II/LP system will not be Man-Rated, and because LP will be provided only in 30 gallon drums, demonstration of system uploading (in 30 minutes) will not include the time to change drums and to observe remote operation protocols. For an objective system, the time penalty for drum changing and remote pumping operations would likely be unacceptable in light of LP system upload/download requirements derived from the AFAS/FARV ORD.

Possible solutions to this issue include a simpler LP coupling interface and a Man-Rating of the LP system that would allow the crew to initiate and control the pumping operation at the drum interface similar to an automotive gas pump configuration. Both the simpler coupling and the Man-Rated system are beyond the scope of the current proof-of-principle program. However, they represent critical issues that should be pursued to insure compatibility with anticipated (FARV) objective system requirements.

RELIABILITY

Early in the ARM II/LP program, a reliability program plan was developed to establish MIL-STD-785B tasks that were to be performed and schedule those tasks over Phases I and II. Technical tasks completed during Phase I include, definition of reliability requirements, development of a preliminary reliability math model and block diagram, allocation of the system requirement to the various subsystem components, and participation in various trade studies related to the LP system.

Mission/Failure Definition

In order to make an assessment of reliability, it is necessary to define the mission of the equipment, as well as what constitutes a chargeable failure. In more detailed analysis, various reliability parameters are often analyzed ranging from the broad umbrella of all malfunctions, to the smaller, subset of failures that cause actual mission loss. For simplicity, the ARM II/LP reliability analysis will be limited to mission failures.

The ARM II/LP mission, as defined by the statement of work, is to upload a full

complement of projectiles and LP into the onboard magazines and storage tank, and then perform a rearm operation by transferring 60 projectiles and 250 gallons of LP to a surrogate rearm port. The transfer of projectiles and LP to the surrogate port must take place in five minutes or less. For reliability analysis purposes, a chargeable failure would be any primary failure that results in the inability of the system to complete the mission. Secondary failures, induced failures and any failures attributable to customer furnished equipment, (e.g. 155-mm projectiles out of specification), are not considered to be chargeable failures.

Component reliability predictions formulated through MIL-HDBK-217 or listed in various data handbooks are typically expressed in terms of hours of operation. Given that the mission of ARM II/LP is to transfer rounds and propellant, it seems prudent to express reliability figures in terms of rounds transferred rather than an operational time period. For analysis purposes, it was therefore necessary to define a conversion factor from hours of operation to rounds transferred. Assuming that, on average, for every 60 rounds transferred, 250 gallons of LP are transferred and accounting for the upload operation, and maintenance activity, a factor of 66.7 rounds transferred per operate hour was developed. This equates to 100 rounds transferred for every 1.5 operational hours.

Math Model/Block Diagram

The preliminary ARM II/LP reliability block diagram is shown in figure 32. ARM II/LP mission reliability is represented by a simple series model, as there is no redundancy built into the system. In other words, all of the components must work for the mission to be successful. The overall system failure rate is computed by simply summing the failure rates of the individual parts. Assuming a standard exponential failure distribution, the ARM II/LP mission reliability is expressed as follows:

$$R = e^{-(t/MRBF)}$$

where, t is the mission time period in equivalent rounds transferred, and MRBF is the assessed mean rounds between failure for the ARM II/LP system.

Given a mission to resupply the equivalent of 60 rounds, and the system MRBF goal of 8,000 rounds, the reliability is computed to be 0.99253. This indicates that there is a 99.25% chance of completing a mission to resupply 60 rounds of ammunition and 250 gallons of LP.

System Requirement/Allocation

There are no quantitative reliability requirements given in the statement of work, however, in the course of early system requirements analysis, a system reliability goal of 8,000 MRBF was self-imposed and allocated to the major assemblies. This preliminary system goal was developed using a bottoms up approach, by combining historical data in the projectile handling arena with preliminary predictions for the LP hydraulics. Hence the allocation to the major assemblies was a direct fallout from the process of establishing a system requirement. The allocation is presented along with the reliability block diagram in figure 32.

Trade Studies

Reliability played an important role in each of the trade studies done to assist in the selection of system components and configuration. In each trade a reliability assessment was made for each of the candidates to be traded, and this assessment was included in the overall weighted rating used to identify the preferred candidate. Reliability was

considered to be one of the most important factors in the trade studies, generally being weighted second only to high risk technical requirements such as material compatibility with LP.

Reliability Issues

Near the end of Phase I the following design issues were identified as possible areas of concern from the reliability viewpoint. These issues will be monitored and more carefully analyzed for impact on system failure rate during the detail design phase.

1. Growing requirements for system sensors - Due to the many uncertainties that surround LP and the concern for safety of both personnel and equipment, there is a tendency to monitor every conceivable parameter in the hydraulic system that might give some indication of the condition of the propellant. The down side of this is that as the number of sensors and controls increases, so does the system failure rate and the frequency of false alarms. Using tools such as failure rate predictions, mission reliability analysis and failure modes, effects and criticality analysis, the reliability engineer will assess the design to ensure that the system is fail safe, and allow for the proper level of redundancy, while still meeting established reliability goals.

2. Limited historical experience base to assess mechanical reliability - Reliability predictions are largely empirical in nature, generally being based on historical data gathered on fielded equipment. Due to the wide selection of available parts, and inherent adaptability of mechanical components to a variety of applications, very limited historical reliability data is available on mechanical equipment. The newness of the LP field of study is especially hampering in this regard, as very little is known about the effects of LP on the reliability of hydraulic equipment. The challenge during phase II of the ARM II/LP program will be to develop a credible reliability prediction for the mechanical equipment. Toward this goal, failure rates will be developed both from tabulated sources, such as NPRD-91, and from prediction analysis methodologies, such as the Reliability Analysis Program (RAP). RAP is an analysis methodology for predicting mechanical part reliability that was developed by GE Aircraft Engines, Evandale, Ohio. RAP is based on a parametric analysis of component mechanical properties that contribute to identified failure modes. The analysis is empirically based, having been developed from historical data gathered on fielded aircraft engines and control systems.

SECONDARY RESUPPLY ITEMS

Field resupply of the future Howitzer will require more than the transfer of projectiles and propellent. Other resupply commodities may include nitrogen, small caliber ammunition, diesel fuel, lubricant, water and food. The traditional method for such secondary items required personnel to leave the protection of their vehicle and pass those items by hand. This method is still an option, although not the ideal solution. As part of the ARM II/LP concept formulation, automated methods for secondary resupply were considered.

For the purposes of this study, secondary items of resupply are segregated into two basic types - bulk stored fluids and all other. The obvious and recommended approach for automated transfer of relatively high volume bulk fluids, such as diesel fuel and perhaps water and nitrogen, is by the same means that LP is to be transferred - via a dedicated pump and plumbing system for each fluid. A separate hose for each fluid would be routed along the docking arm in parallel with the LP hose, and the docking head would be configured with additional couplings to automate connection and transfer. The secondary fluid transfer activities could thus occur simultaneously with LP and

projectile transfers. The method of storage employed for each of these fluids on the resupply vehicle would depend on whether the substance is a gas or a liquid, and also whether the resupply vehicle itself consumes that commodity (diesel fuel, for example). These considerations would determine whether the storage tank is a pressure vessel or not, and whether that tank would feed the resupply vehicle as well, or just the Howitzer.

With regard to solid commodities, or lower volume liquids stored in discrete units, the optimal solution for totally automated transfer would require no additional equipment and instead utilize the existing projectile storage magazines and transfer conveyor. The recommended concept for accomplishing this is by simply packaging such secondary resupply items into special hollow, projectile shaped canisters. Loose items such as ammunition, lubricant, water, food, etc. can be inserted into these hollow canisters and labeled with 2-D matrix symbology at the point of origin or the depot. These would be uploaded into the resupply vehicle's magazines as if they were projectiles, and the projectile label readers would scan and identify each canister as it arrives at the storage magazines. Onboard inventory and storage location information would be automatically maintained by the computer system, and specific canisters can be called up and transferred at will, even intermixed with projectiles. The exact same approach can be utilized for storage within the Howitzer. Once the inventory has been transferred to the Howitzer and placed in storage, the crew can later access the magazine to obtain those specially marked projectiles as required. Similar canisters can be designed as pressure vessels to hold gases such as nitrogen, and have couplings accessible on the top or side.

OPERATING ENVIRONMENT WITH LP

The introduction of LP as a material to be transported on the Resupply vehicle must be considered from the point of view of crew safety and equipment maintainability. Since LP presents a low level health hazard to the crew if they inadvertently become exposed to the material, certain ancillary equipment should be incorporated into the vehicle to provide a means of treating any crew exposure. For example, a water source serving a shower and eye wash should be included on the vehicle, and supplies to treat ingestion or inhalation of LP should be added to the first aid kit.

LP itself is an oxidizing agent and has deleterious effects upon most metals and certain non-metals upon extended contact. For this reason, care must be exercised when selecting materials in and around an LP handling system.
Provisions must also be made to contain any LP that could leak from the system due to breakage or malfunction and prevent it from coming in contact with vulnerable materials or the crew.

The most valuable contribution toward safe handling of LP would be in the proper training of personnel. This includes procedures for dealing with human health hazards as well as proper cleanup methods for any LP spilled on or around the resupply vehicle.

CONCLUSIONS

1. The Artillery Rearm Module with Liquid Propellant (ARM II/LP) proof-of-principle preliminary design satisfies all objectives of the contract statement of work (SOW).

2. The system requirements document provides a compilation of SOW requirements and self-imposed goals which together form a concise and complete definition of the ARM II/LP system design criteria.

3. The design approach for the liquid propellant handling system is simple, conservative (low risk), utilizes current state of the art pumping technology, and was selected through

the tradeoff study as the best technical solution.

4. The side by side projectile magazine positioning choice enhances overall system packaging and simplifies conveyor deployment while maintaining high commonality with previously designed and tested ARM II/Unicharge magazines.

5. The overall system arrangement efficiently utilizes available space and integrates well with the MLRS carrier test bed vehicle.

6. The proof-of-principle system will demonstrate technologies that are inherently applicable to future artillery requirements.

7. The automated resupply of secondary items is conceptually and technically feasible, and should be assessed further in future development.

8. Areas of technical risk include: high rate pumping effect on LP, remote LP coupling actuation, LP uploading, and ease of conveyor docking.

RECOMMENDATIONS

The recommended action submitted for consideration by ARDEC is the acceptance of the Artillery Rearm Module with Liquid Propellant proof-of-principle concept, as presented at the July 1993 preliminary design review and described in this report, and the approval of funding for completion of the detailed design, fabrication, and testing.

Table 1. Tradeoff matrix of available LP transfer methods

CHARACTERISTICS EVALUATED

System Options	Safety	Hardware Complexity	Development Cost	Reliability	Recurring Cost	Purging	Weight	Tank Unload	Totals
1. Pressurized Bladder	3	2	3	3	2	1	2	1	17
2. Pressurized Storage Tank	2	3	4	4	3	4	2	2	24
3. Pump	4	4	5	4	3	3	3	4	30

Conclusion: Transfer Of LP Using A Pump Was Selected Based On Lower Operational Pressure And Safety

Table 2. Tradeoff matrix of LP storage concepts

Requirement or Characteristic Evaluated	Weighting Factor	Tank Configuration					
		Single Tank	Pressurized Bladder	Two Tanks Manifolded	Two Tanks with Pump Between	HAZMAT Drums in Series	HAZMAT Drums in Parallel
Survivability	2	2	1	4	4	3	5
Capability to be Flushed	4	5	2	4	4	1	1
Space Claim	5	5	3	4	4	1	1
Support Equipment	2	5	1	4	4	1	1
Development Cost	3	5	1	4	4	3	3
Recurring Cost	1	5	1	4	4	3	3
Plumbing Complexity	3	5	4	3	3	1	1
Safety	5	3	1	3	3	5	5
FARV Adaptability	2	1	1	4	5	2	2
Instrumentation Complexity	2	5	4	4	4	1	1
Reliability	4	5	1	4	3	3	4
Technical Risk	4	5	1	4	4	3	3
Efficiency (LP Waste)	3	5	3	4	4	1	1
Maintainability/Accessability	4	5	3	4	4	2	2
Weight	1	5	4	3	3	1	1
Total Weighted Rating		201	91	171	169	99	107

Tank Rating Scheme: 1 = Least Desirable, 5 = Most Desirable

Weighting Factor: 1 = Least Important, 5 = Most Important

Table 3. Tradeoff matrix for LP pump technology selection

Requirement or Characteristic Evaluated	Weighting Factor	Pump Types								
				Gear			Centrifugal			
		Diaphragm	Lobe	Rotary	Magnetic Drive	Flexible Impeller	Mech. Seal Self Priming	Magnetic Drive	Canned Motor	Peristaltic
Reversible	Y/N	N	Y	Y	N	N	N	N	N	Y
Demonstrated LP Pumping	Y/N	Y	N	N	N	N	N	Y	N	N
Dry Operation	5	5	5	3	2	*	3	2	*	5
Self Priming Capability	3	5	3	4	4	3	3	3	5	5
Temp. Capability - ARM II Req.	5	4	5	5	5	*	5	5	5	5
Temp. Capability - FARV Req.	4	1	5	5	5	*	5	2	5	3
Leak Proof	5	5	2	2	5	2	2	5	5	5
Proven, off-the-shelf technology	3	3	5	5	5	3	5	5	5	5
Pulsating Flow	3	4	4	5	5	5	5	5	5	2
Development Cost	3	3	5	5	5	5	5	5	5	5
Recurring Cost	3	1		5	2	5	5	4	1	4
Size	3	3	5	5	5	5	5	5	4	1
Weight	3	3	4	5	5	5	4	5	5	1
Reliability	4	2	4	4	5	4	4	5	5	5
Efficiency	3	5	4	4	4	4	3	4	3	2
Technical Risk	4	2	1	1	1	1	4	1	1	4
Material Compatibility	5	5	5	5	5	3	5	5	5	5
Shear Heating	5	5	4	3	3	5	3	3	3	5
Adiabatic Compression	5	4	*	*	*	5	5	5	5	3
Drainability	4	3	4	4	1	4	3	3	1	4
Cavitation	5	5		3	2	5	5	4	5	5
Total Weighted Rating		278	*	*	*	*	309	297	*	304

Pump Rating Scheme: 1 = Least Desirable, 5 = Most Desirable   Weighting Factor: 1 = Least Important, 5 = Most Important

Y/N - Characteristics rated "Yes" or "No" are not included in the rating total but will be considered in making the final pump selection.

* Indicates a prohibitive characteristic that caused the pump to be dropped from further consideration.

Table 4. Operational task analysis for ARM II/LP

TASK: UPLOAD from HAZMAT DRUM

ACTION PERFORMED	HARDWARE INTERFACE	FEEDBACK RECEIVED	HFE/SAFETY/ ENVIRONMENTAL ISSUES	COMMENTS
Turn ON System	Cab System Panel	Power "ON" Indicator-Changing		Same as ARM II/UNI
Select/Enter: - UPLOAD - LP - HAZMAT - Desired LP Qty Install adapter(s) in HAZMAT bungs	Remote HandsetHAZMAT drums	Menu Options - Upload Status Summary - Procedural PromptsProper Installation		Same as ARM II/UNI (except for LP and HAZMAT menu options)
Insert HAZMAT Tube into adapter	HAZMAT drum Adapter	Coupling Connection	Leak-free coupling required	
Initiate "Pumping"	"START" Button, Remote Handset	Change in LP QTY and % Loaded status on Remote Handset		Pumping inhibited if system detects "Empty Pump well". Handset prompt to "Prime" via Maintenance Panel button.
Pumping continues until: - HAZMAT empty - ARM "FULL" - "Qty" loaded - Fault detected	LP Control System	Pump stopped and Remote Handset Prompt indicates "Install Next Drum, Upload Complete, Etc."	Operator(s) required to be remote from HAZMAT area during pumping. E-Stop will stop Pump (and magazine) operation.	
Remove tube and adapter and install in next drum (if required) or stow if finished				

Table 4. (cont)

TASK: DOWNLOAD TO HAZMAT DRUM

ACTION PERFORMED	HARDWARE INTERFACE	FEEDBACK RECEIVED	HFE/SAFETY/ ENVIRONMENTAL ISSUES	COMMENTS
Turn ON System	Cab Sys. Panel	Power "ON" Indicator		Same as ARM II/UNI
Select/Enter: - DOWMLOAD - LP - HAZMAT - Desired LP Qty	Remote Handset	Menu Options - Upload Status Summary - Procedural Prompts Coupling indication	Drip-less coupling required	Same as ARM II/UNI (except for LP and HAZMAT menu options)
Install HAZMAT adapter/filler tube into drum	HAZMAT Drum			More than one set of adapter/ sensor would expedite operations with HAZMAT Drums
Initiate "Pumping"	"START" Button, Remote Handset	Change in LP QTY and % Downloaded status on Remote Handset	Pump/coupling interlocked to prevent "uncoupled" pumping	Pumping inhibited if system detects "Empty Pump well". Handset prompt to "Prime" via Maintenance Panel button.
Pumping continues until: - HAZMAT FULL - ARM "EMPTY" - "Qty" unloaded - Fault detected	LP Control System	Pump stopped and Remote Handset Prompt indicates "Drum Full, Install Next Drum, ...etc."	Operator(s) required to be remote from HAZMAT area during pumping. E-Stop will stop Pump (and magazine) operation.	
Remove tube and adapter and install in next drum (if required).				

Table 4. (cont)

TASK: CONVEYOR DEPLOYMENT

ACTION PERFORMED	HARDWARE INTERFACE	FEEDBACK RECEIVED	HFE/SAFETY/ ENVIRONMENTAL ISSUES	COMMENTS
ARM vehicle positioned to approx distance/orientation	Vehicle motion and steering controls	TBD alignment cues and/or experienced judgement	Alignment distance criteria based on	
Release travel lock	Left rear sponson area	Position of release lever, latch, etc.	Reach/Visual access by 5th percentile crew	
Retract transfer conveyor to release LP coupling	Control mechanism is TBD	Motion and separated condition of LP coupling	Protection from pinch and other mechanical hazards	
Lift and position docking head/conveyor to 90^{o} deployed position	Diagonal bar handleson on each side of docking head	Conveyor will auto latch in 90^{o} position.		
Final alignment of vehicle for docking.	Vehicle motion and steering controls	Alignment of TBD vehicle/ docking head features for proper distance/orientation		Vehicle alignment procedures and/or req't for hardware cues/features have not been defined.
Position docking head for engagement with mating port.	TBD handles on docking head structure	TBD alignment features on docking head and mating vehicle/port surfaces		
Attach/actuate latches to secure docking head	TBD latch, fastener, lever, etc.	Latch closed and docking head aligned and secured.		
Align and engage LP coupling to port	Electro-mechanical actuation.	Prompt to "initiate engagement" on Handset display	Elec/mechan indicator to verify "engagement".	Interlock to pump operation reduces potential for leak/spill.

Table 4. (cont)

TASK: ABNORMAL (LP Temp/Pres) OPERATION

ACTION PERFORMED	HARDWARE INTERFACE	FEEDBACK RECEIVED	HFE/SAFETY/ ENVIRONMENTAL ISSUES	COMMENTS
(System sensors detect Level 1 alert condition and level 1 alarm is automatically initiated)	TBD (audio) alarm device and (video) indication on Remote Handset	Audio alarm and prompt/message on handset display.	Purpose is to alert local personnel of potential hazard condition	
(Handset) operator has option to reset alarm or to manually initiate tank drain /water purge emergency action.	Remote Handset	Alarm is extinguished.		
	Remote Handset and Maintenance Panel	Alarm continues and tank drain opens to external water tank and water is pumped into ARM LP storage tank for TBD minutes until 50/50 mixture is achieved.		
(System detects Level 2 condition and initiates level 2 audio alarm plus water purge/tank drain function)	Automatically done by electronic control unit.	Alarm indication and hazard procedures displayed in Prompt/Message area of handset display.	Level 2 audio alarm should be distinctly different in tone/volume/intensity and is not defeatable by the crew.	

Table 5. Preliminary hazard analysis for ARM II/LP

HAZ No.	HAZARD DESCRIPTION	RAC	Recommended Hardware, Software Change or CAUTION/WARNING Equipment Marking	COMMENTS
C-1	Back/leg injury caused by unsafe lifting requirements	III-C	Equilibration of articulated conveyor segments; Appropriate handles (size, no., location)	Proposed design of Transfer Conveyor equilibrates weight to approx 50 lbs.
C-2	Finger/hand injury at pinch points of conveyor joints	III-C	Guard/protect potential pinch points and apply CAUTION marking around probable areas	
C-3	Hand/Arm injury from entanglement with conveyor belts, pulleys, etc.	II-D	1. Minimize exposure of moving conveyor components 2. Provide Emergency-Stop controls at convenient locations around conveyor. 3. CAUTION instructions in training procedures.	The ARM II/UNI conveyor design incorporates all of these Safety features. Similar Safety design is anticipated for this application.
C-4	Damage to conveyor resulting from vehicle motion during transit.	III-C	Appropriate travel restraints for stowed position of conveyor.	Current concept provides a stowage "receptacle" at rear of left sponson to secure docking head .
C-5	Ground personnel injured by impact from (remotely controlled) moving conveyor.	III-D	Remotely controlled movement of transfer conveyor should be accompanied by audio alarm to alert crew of local hazard unless movement is sufficiently slow to afford reasonable response time and necessary evasive action by local ground/on-vehicle personnel.	NOTE: This remote operation capability is NOT included as part of the baseline ARM II/LP system but is to be incorporated in additional system options currently being proposed.

C = CONVEYOR LP = LIQUID PROPELLANT E = ELECTRONICS M = MAGAZINES

Table 5. (cont)

HAZ No.	HAZARD DESCRIPTION	RAC	Recommended Hardware, Software Change or CAUTION/WARNING Equipment Marking	COMMENTS
LP-1	Ingestion, Inhalation or Eye/ Skin contact of LP by Crew	III-D	1. Location/shielding of LP components to minimize crew contamination in event of conduit or fitting failure/leak, etc. 2. Water source with shower and eye-wash station should be available at all sites where LP is stored, handled or transferred.	The shower/eye-wash station is a firm requirement for the objective system, but could be implemented as a separate piece of support equipment for the purposes of ARM II/LP testing.
LP-2	Uncontrolled fume-off, fire or explosion induced by cavitation, elevated pressure and/or temp.	I-D	1. LP system design to include temp/pressure monitoring capability with automatic system alerts to advise crew of potential hazard and instruct or automate shut-down/corrective action procedures. 2. Audio alerts should be used to alert crew to potentially hazardous condition to enable their safe/timely exit.	Monitoring system should detect abnormal rate changes as well as threshold limit violations which are sufficiently below critical values to allow responsive action and to avoid serious consequences.
LP-3	Unnecessary purging of LP caused by component failure (sensor, valve, etc.) resulting in crew/equip. exposure.	III-C	Valve position feedback to LP controller should be based on actual valve position and <u>NOT</u> on commanded position. This avoids inappropriate response to fault/failure conditions.	
LP-4	Environmental, crew and equip. exposure to LP fluid resulting from controlled pressure relief or minor plumbing leaks.	III-D	Containment tank/basin to collect/contain relief valve discharge and routine leaks and have means of draining or pumping to waste container for disposal. Volume of basin should handle total system capacity.	
LP-5	Temporary/permanent hearing loss from exposure to pump/ motor noise.	III-C	Accoustic baffle/shield/containment to reduce ambient exposure to safe, OSHA/MIL-STD 1474 levels.	Noise level is TBD. Crew exposure to pump/motor noise may only occur during maintenance or non-routine test/debug tasks.

C = CONVEYOR LP = LIQUID PROPELLANT E = ELECTRONICS M = MAGAZINES

Table 5. (cont)

HAZ No.	HAZARD DESCRIPTION	RAC	Recommended Hardware, Software Change or CAUTION/WARNING Equipment Marking	COMMENTS
E-1	Personnel shock hazards due to unprotected terminals (on power supplies), energized male connector pins, or improperly grounded conductive surfaces.	I-D	Electrical conductors, terminations, connectors and grounding schemes to be compliant with MIL-STD-454, Requirement 1- Personnel Safety.	
E-2	Electrically induced ignition of LP fluid due to failure/short circuit in electrical component in contact with LP fluid.	II-D	All electrical components in contact with pressurized LP fluid should be of "explosion-proof" type, i.e., should not allow spark or heat to come in contact with LP fluid under any failure modes.	May require current sensing, BIT logic or circuit breakers for each device.
E-3	Crew member outside vehicle subject to <u>unexpected</u> hazardous conditions in the event of system malfunction that results in controlled/ uncontrolled LP discharge.	III-D	Detection of critical system failures/malfunctions that might contaminate or otherwise endanger crew members should be accompanied by audio alert to warn personnel of potential hazard in time for quick response.	Remote deployment of conveyor should also alert ground personnel of powered moving equipment. A different audio signal should be used for this alert to avoid any possible confusion with the impending hazard indication.

C = CONVEYOR LP = LIQUID PROPELLANT E = ELECTRONICS M = MAGAZINES

Table 5. (cont)

HAZ No.	HAZARD DESCRIPTION	RAC	Recommended Hardware, Software Change or CAUTION/WARNING Equipment Marking	COMMENTS
M-1	Arm/hand injury from contact or clothing entanglement with moving arms, gears or other magazine components.	II-D	All magazine moving parts to be protected from accidental crew contact during normal operational conditions. Test, debug and O-level maintenance access to these areas should be controlled by an electrical interlock (overrideable at the Maint Control Panel) and/or CAUTION/WARNING marking on access doors or covers.	All such "Access to hazardous areas" WARNINGS should also be documented in Training programs/ documentation.
M-2	Mechanical damage to magazine/handoff components caused by system continuing to operate after some failure has occurred.	III-D	BIT diagnostics to detect abnormal current draw or other symptoms of system problems that should automatically stop system or communicate alert to the crew.	

C = CONVEYOR LP = LIQUID PROPELLANT E = ELECTRONICS M = MAGAZINES

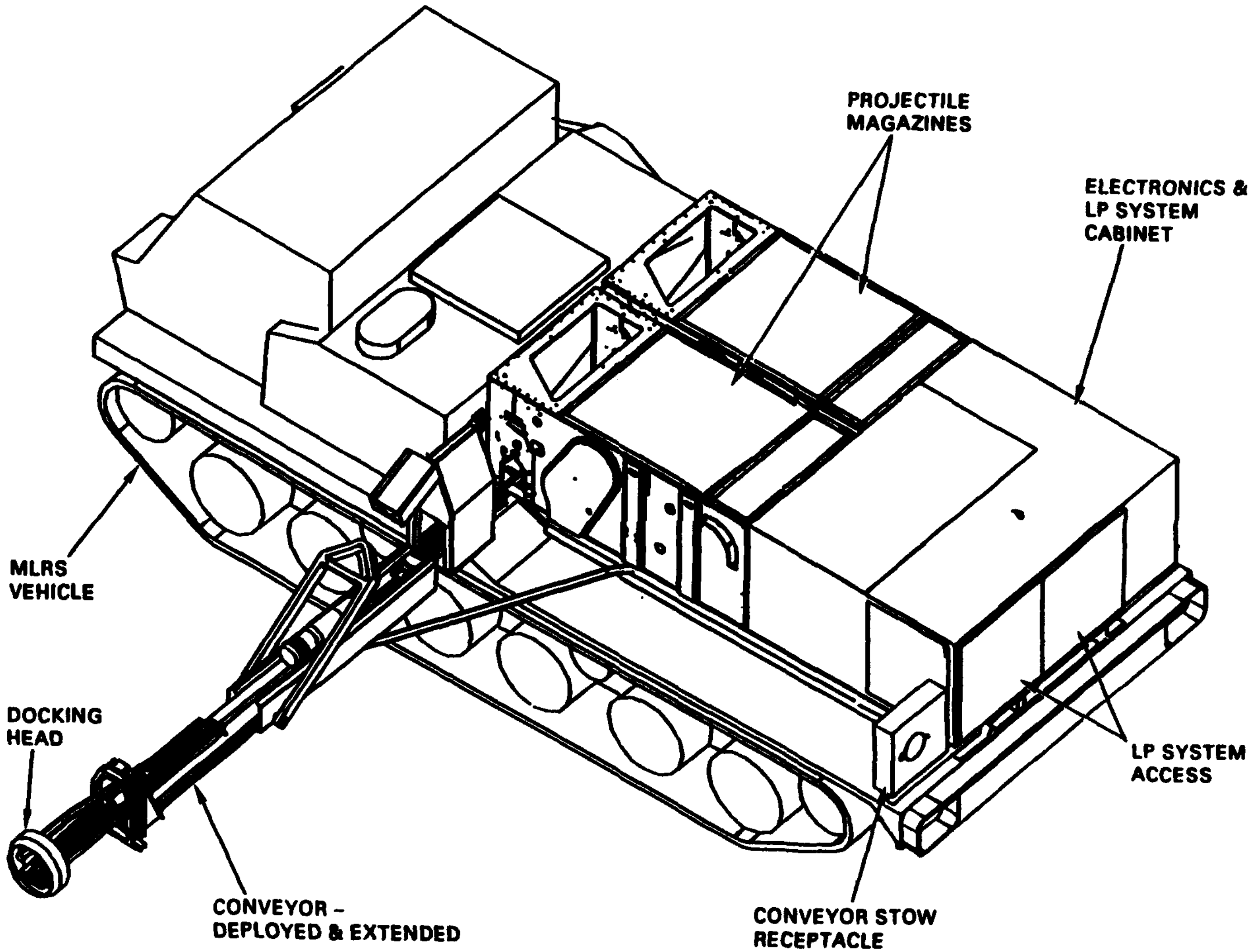


Figure 1. ARM II/LP system mounted to a Bradley MLRS vehicle

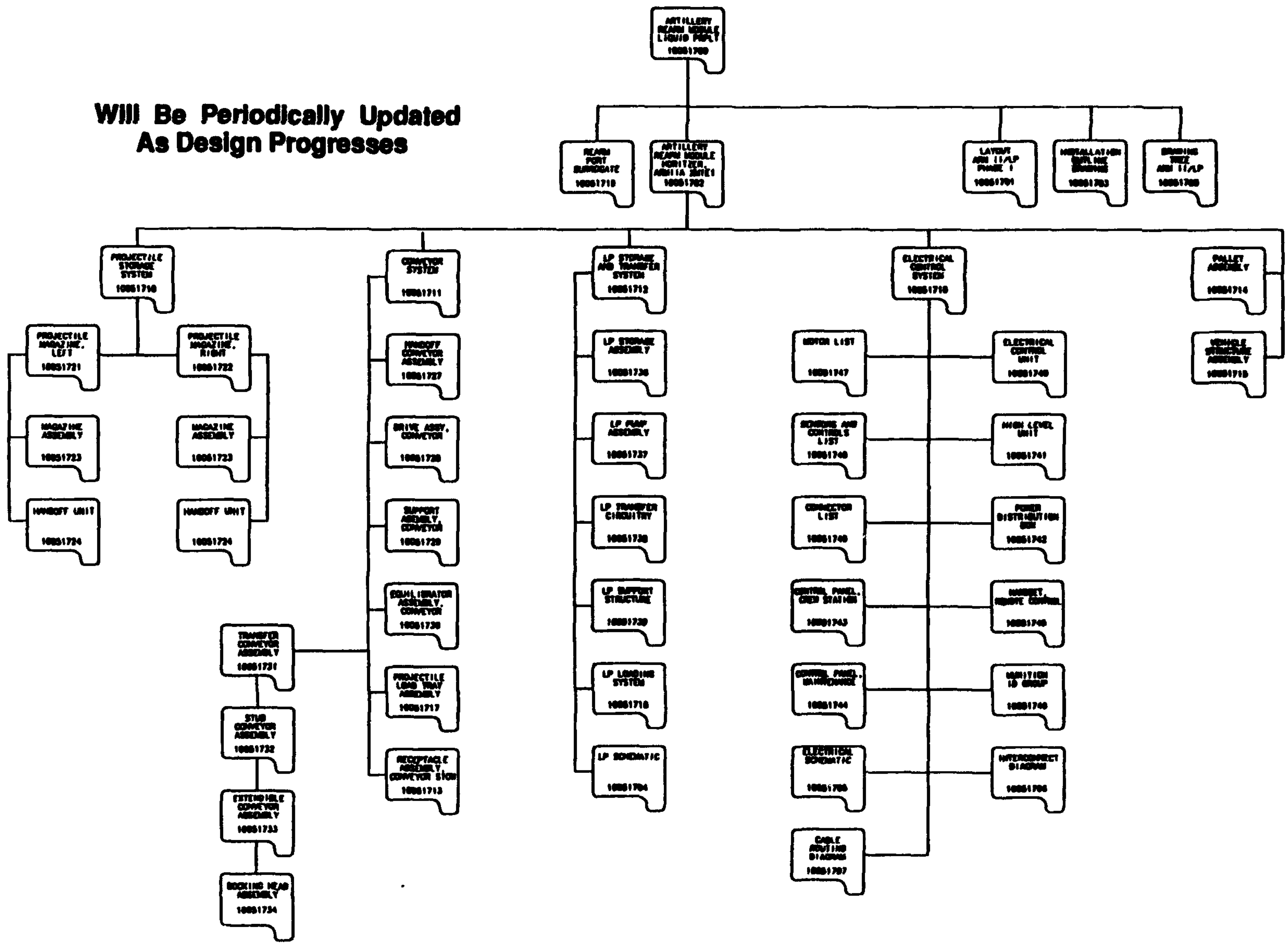


Figure 2. Planned ARM II/LP drawing architecture

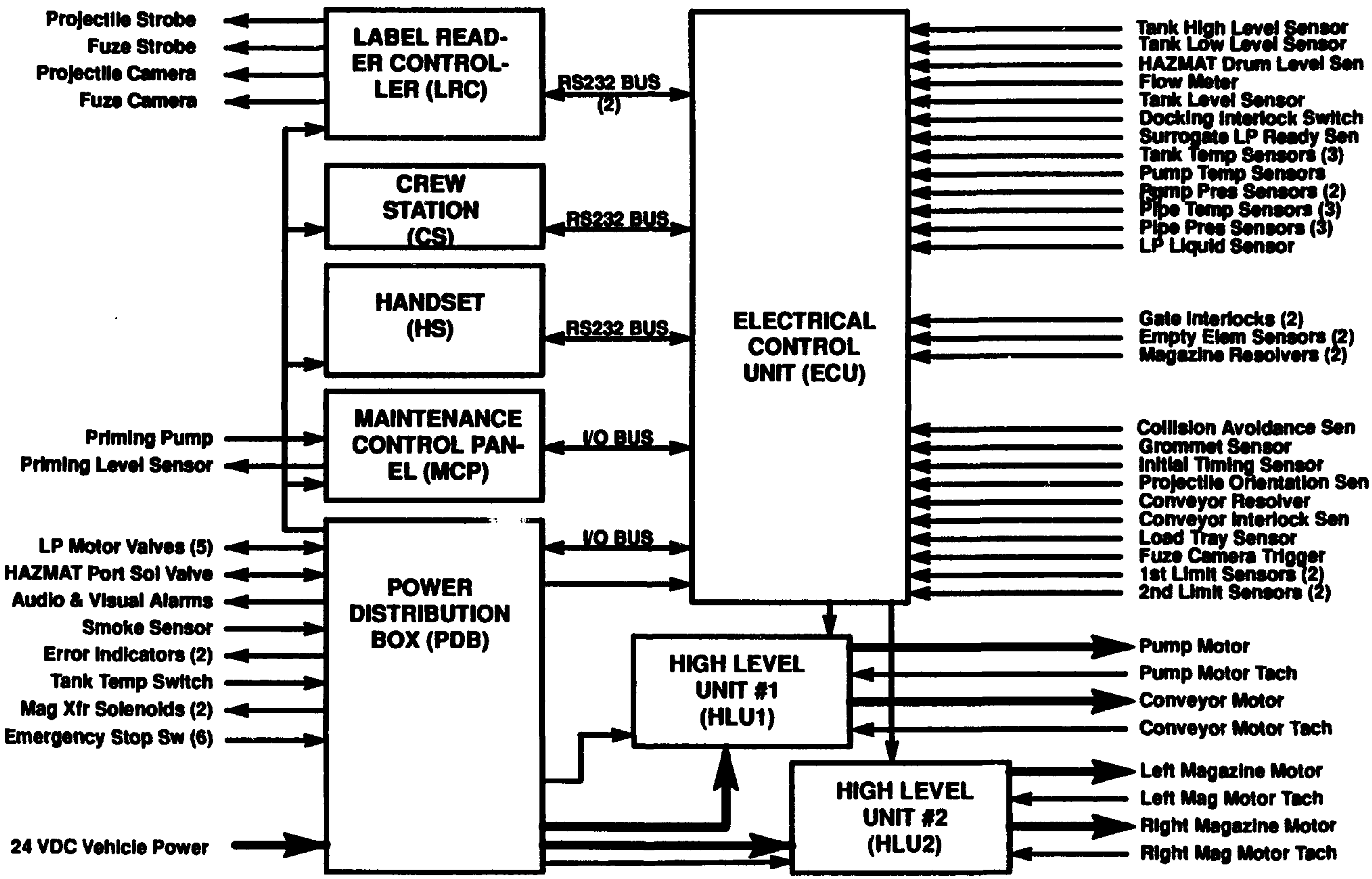
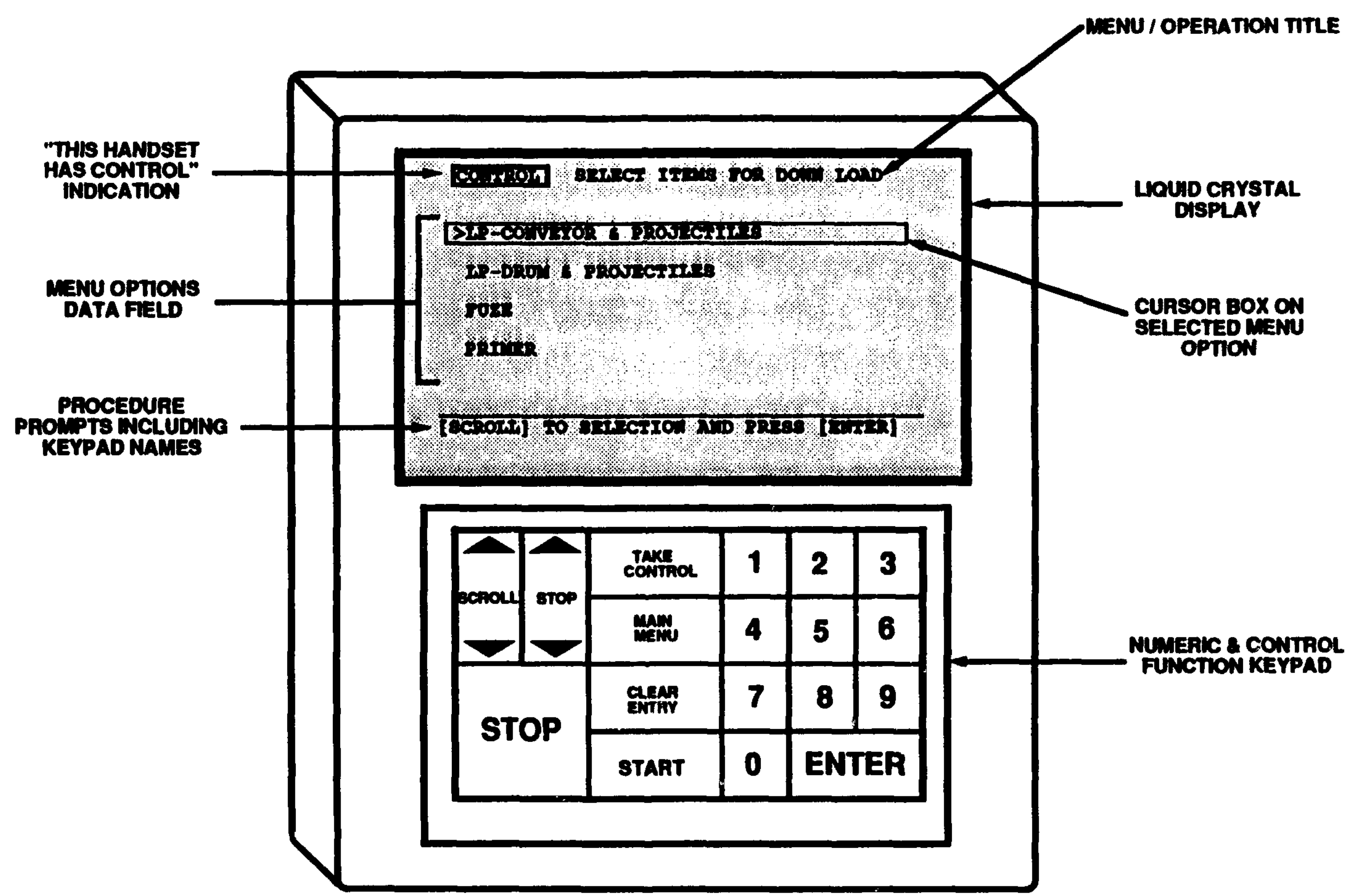


Figure 3. Primary electrical components and interconnection diagram



F' ..e 4. ARM II remote handset for control/display interface

- **SCROLL** — Moves Cursor Box Up/Down To Indicate "Selected" Menu Option
- **PAGE** — Displays Forward/Back Pages In Multi-Page Listing
- **TAKE CONTROL** — Gives This Handset Control Of System Operation Functions (Upload/Download)
- **NUMERICS (0 - 9)** — Identification Of Order Quantities or Volumes
- **ENTER** — Second Step Of Option Selection From Menu. Finalizes Current Selection
- **CLEAR ENTRY** — Erases Displayed Quantity In Order Column
- **MAIN MENU** — Returns Display To Top Level Menu (Unless Download Is In Process At This Handset)
- **START** — Starts Conveyor And LP Pump Motors (If This Terminal Has Control)
- **STOP** — Stops All Motors And Actuators

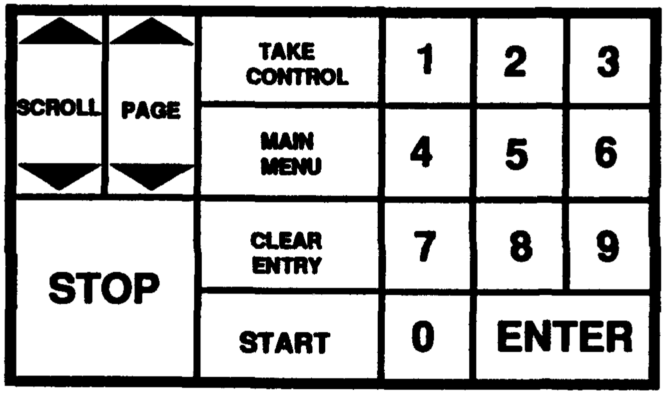


Figure 5. Keypad functions employed by the ARM II remote handset

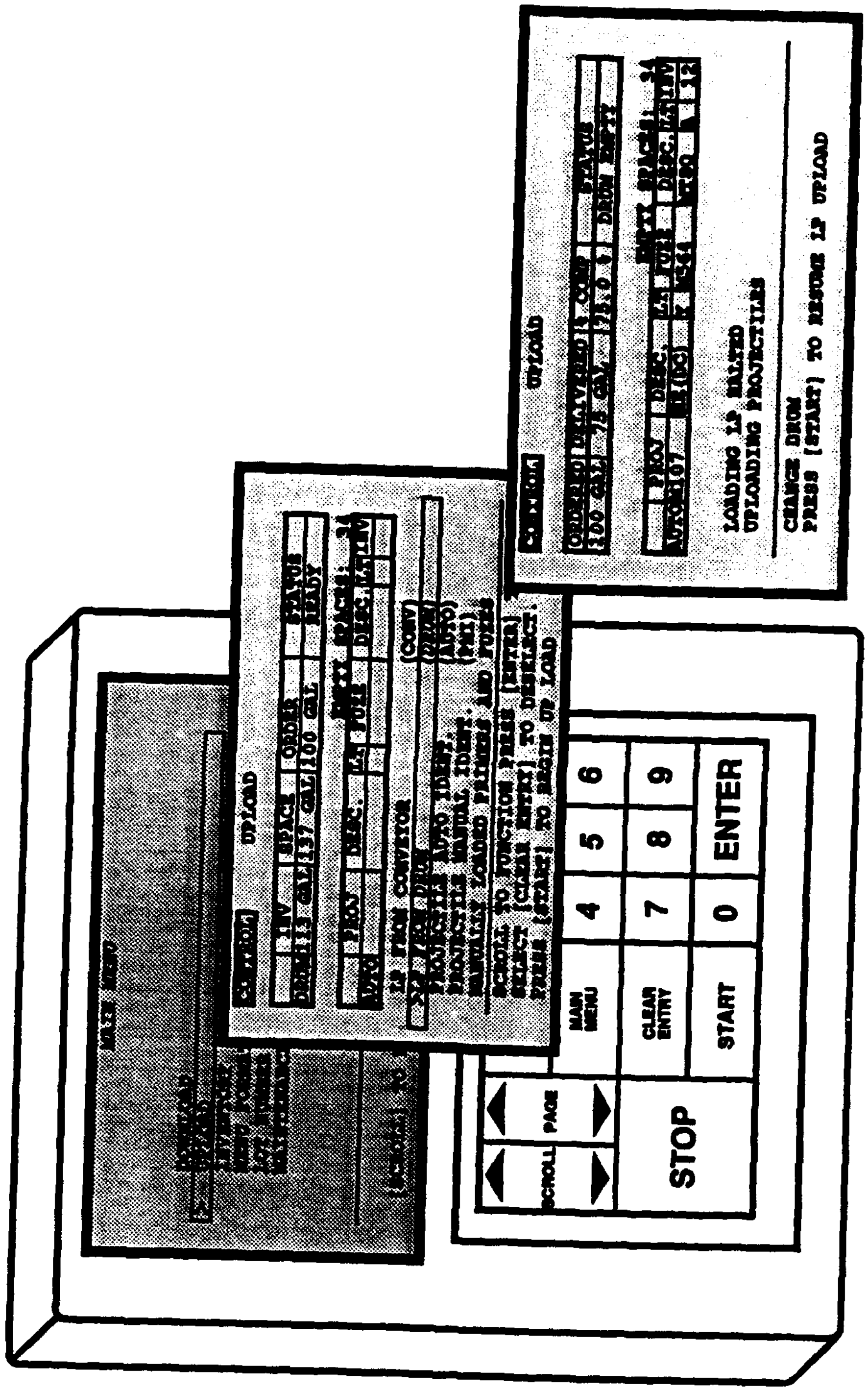


Figure 6. Menu display for projectile and LP upload

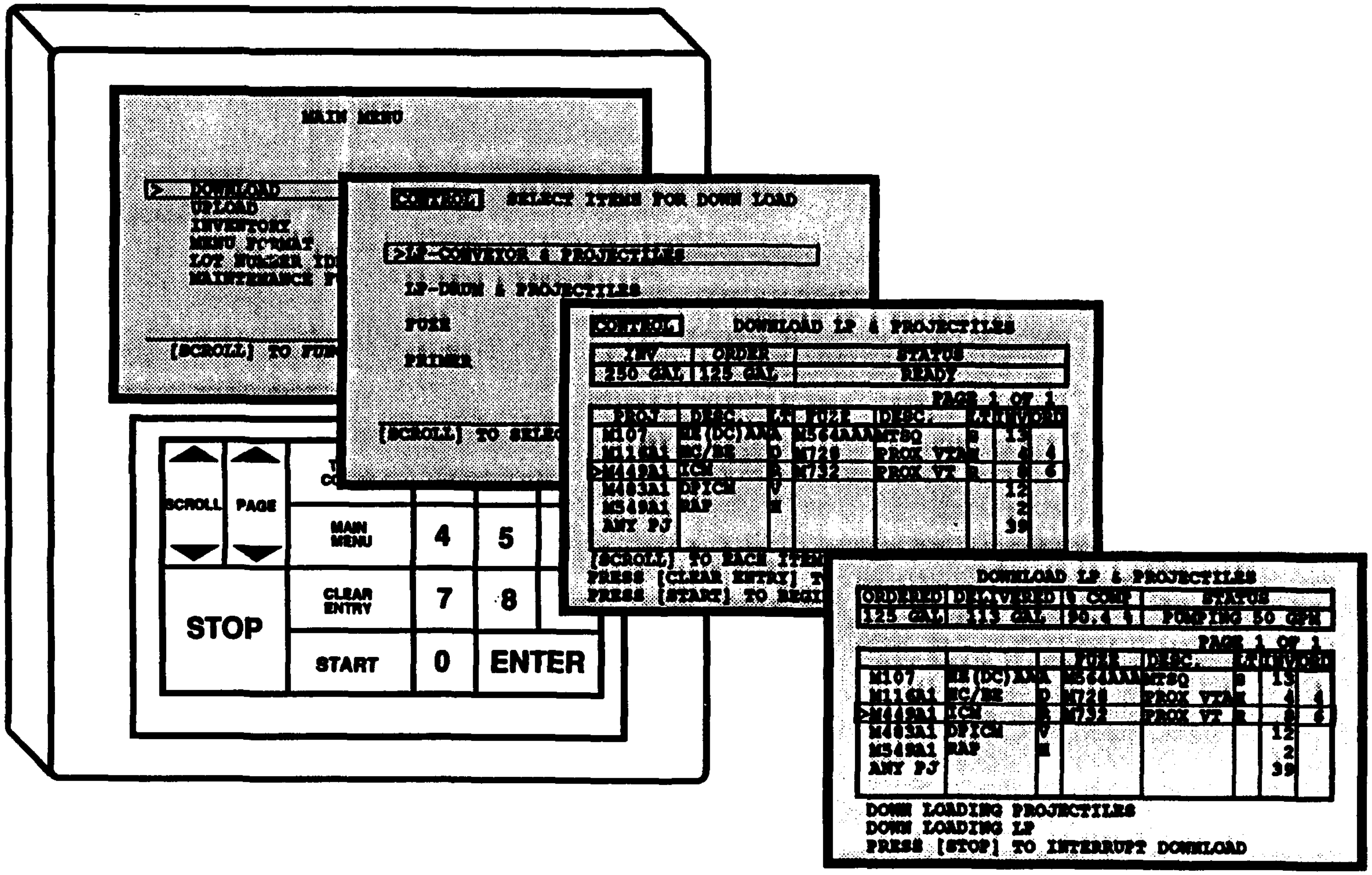


Figure 7. Menu display for projectile and LP download

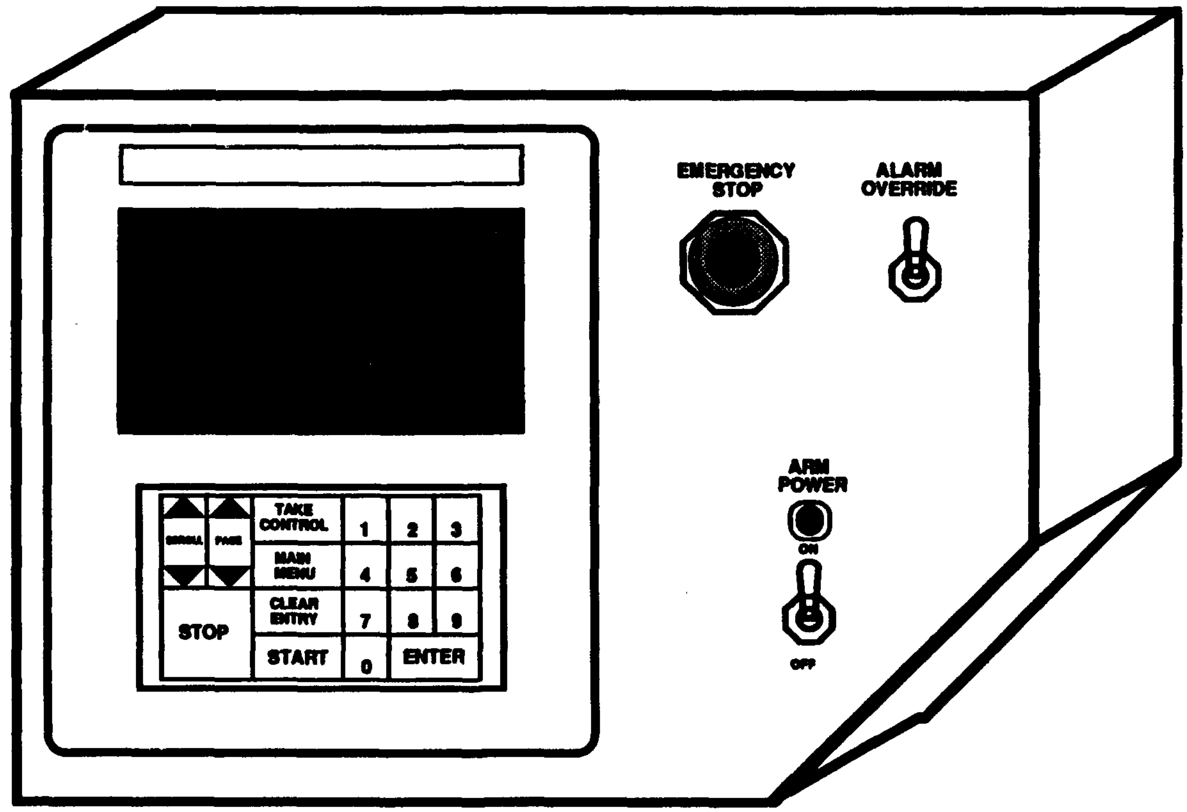


Figure 8. Crew station interface for system operation from inside the Bradley cab

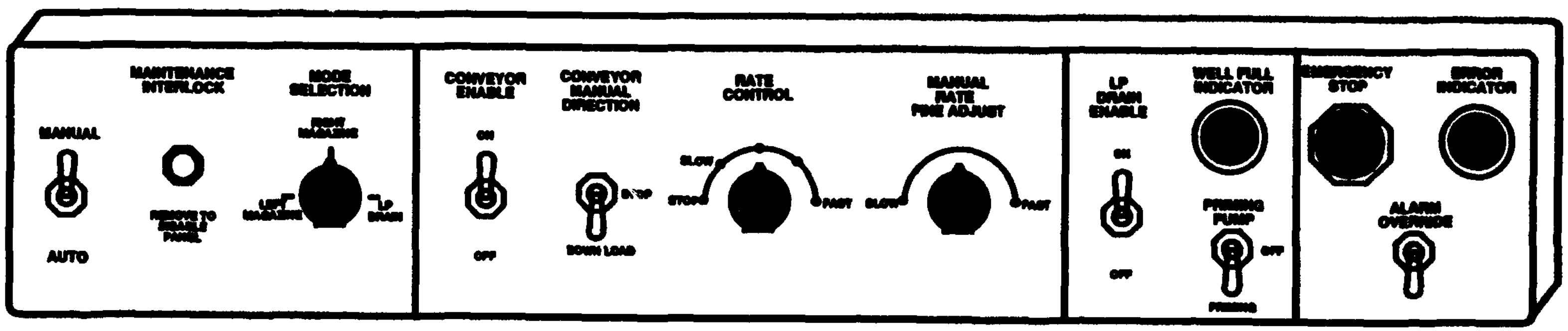


Figure 9. Maintenance control panel for system operation outside of normal rearm activity

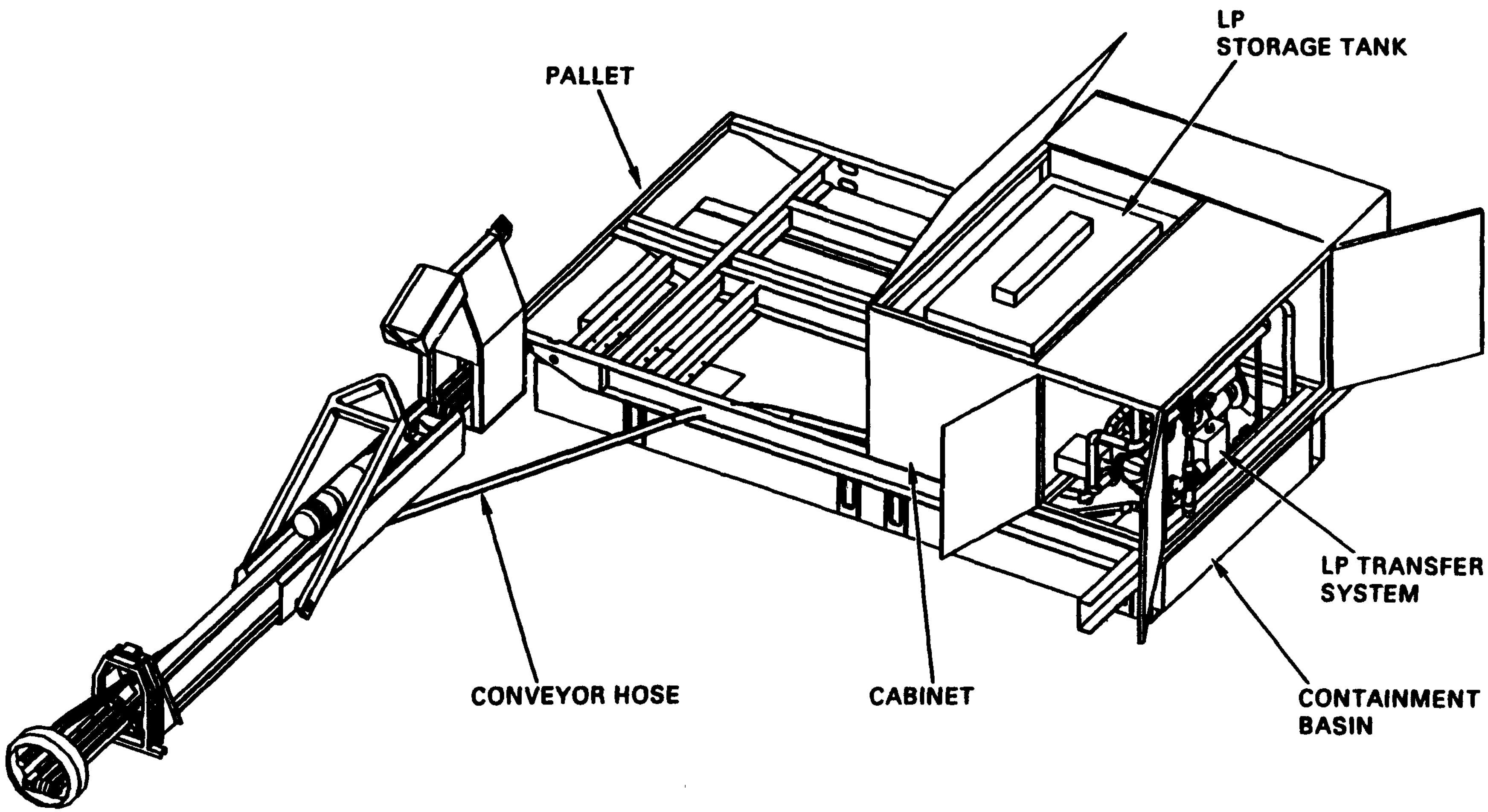


Figure 10. LP transfer and storage system for ARM II/LP.

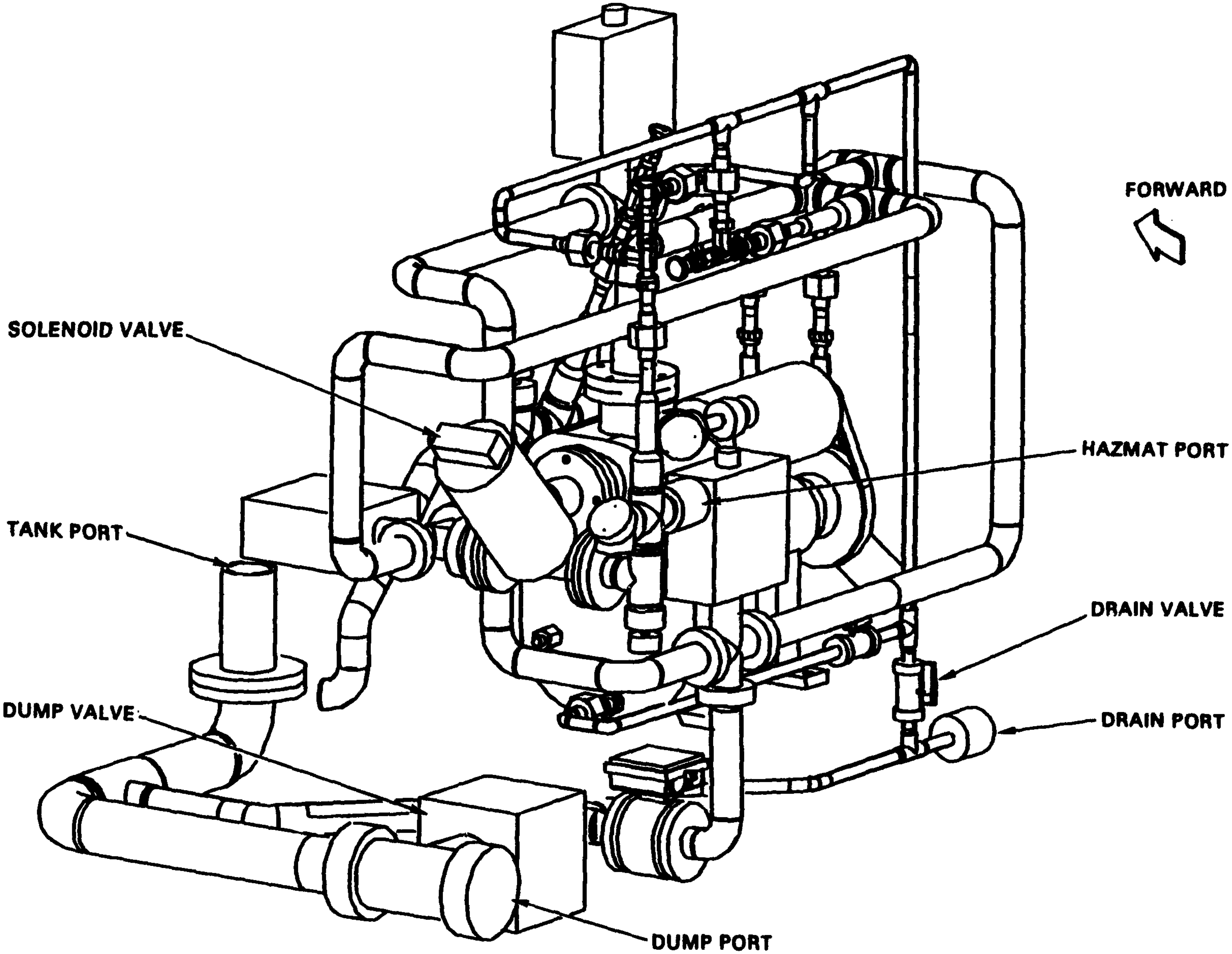


Figure 11. LP transfer network aft view looking forward

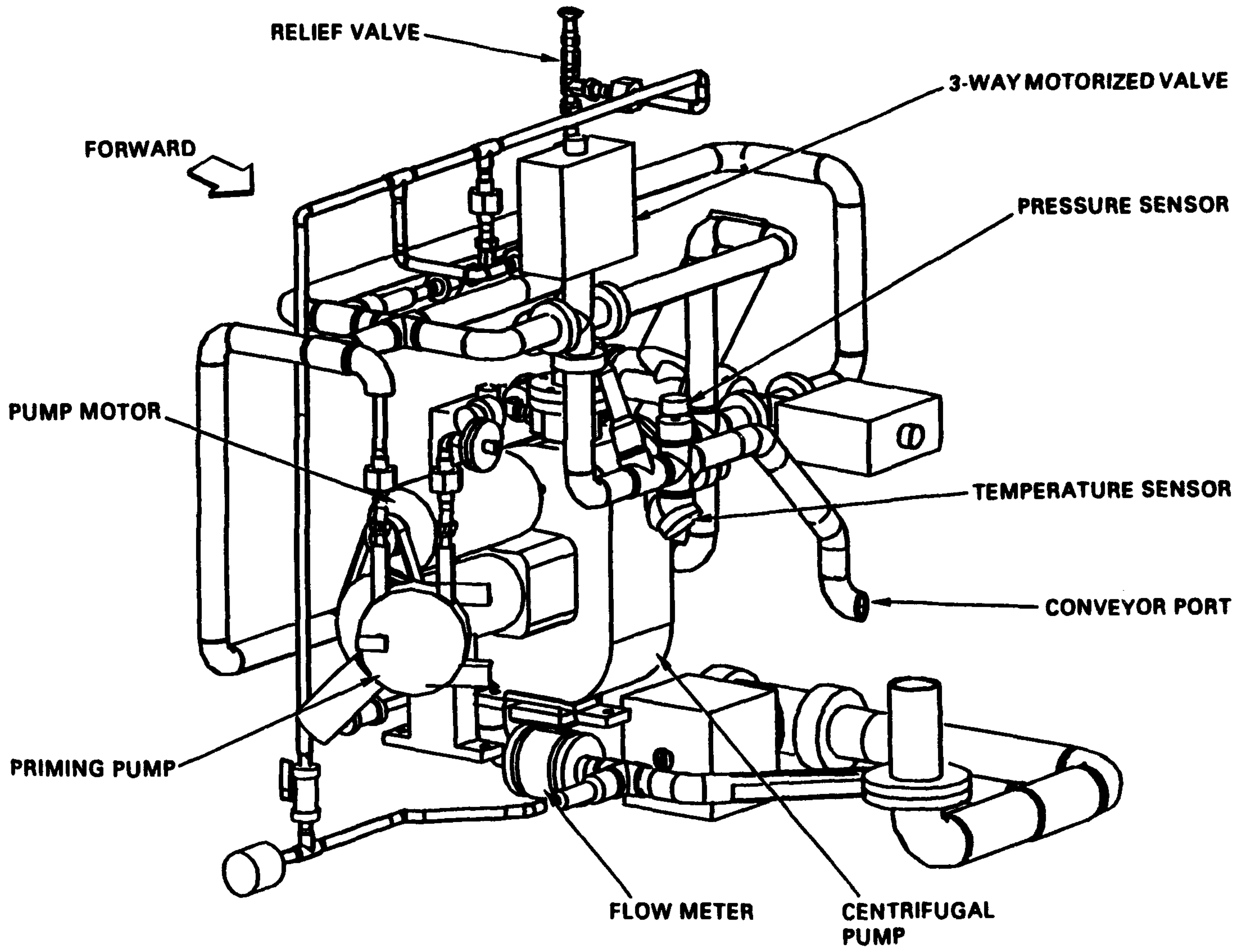


Figure 12. LP transfer network forward view looking aft

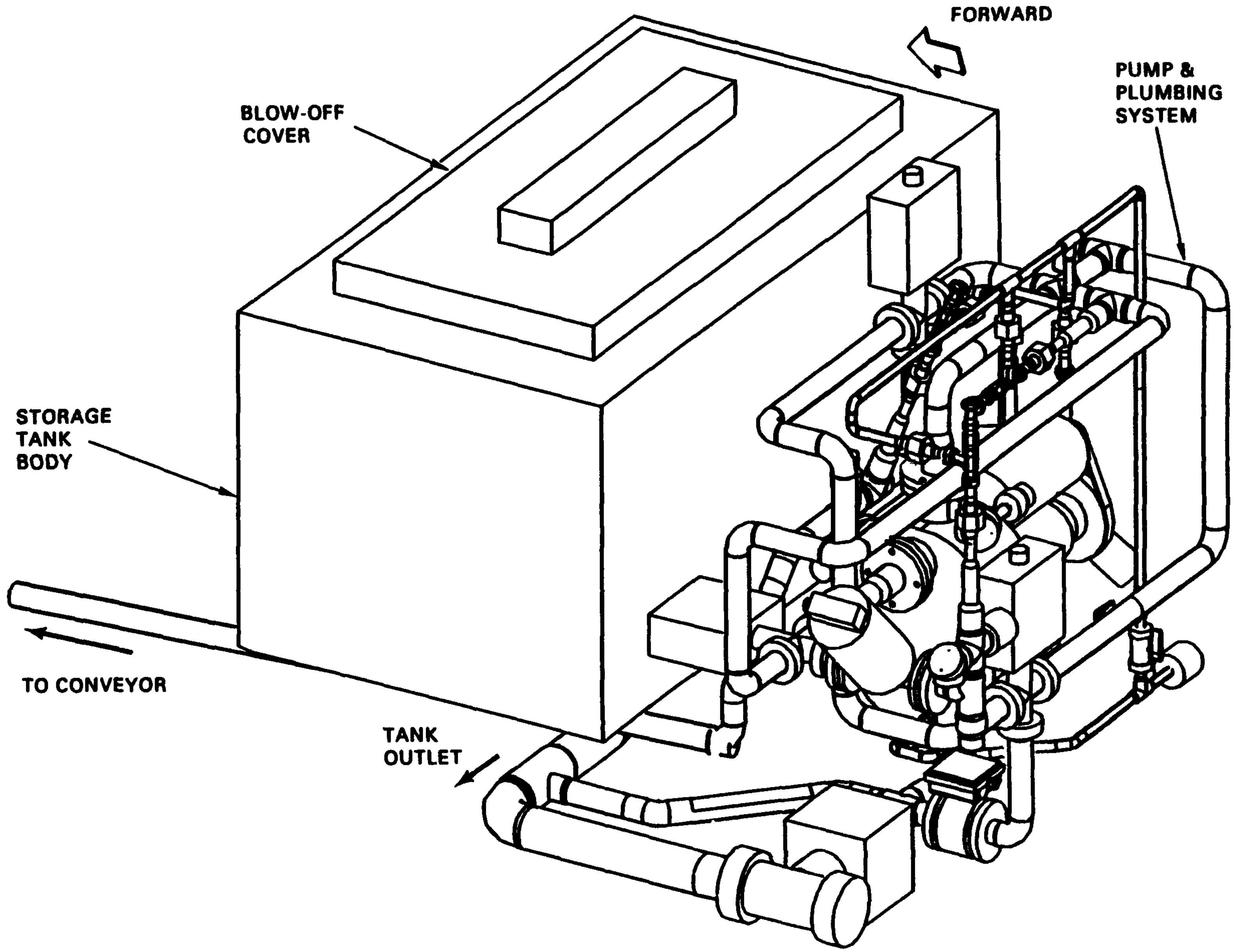


Figure 13. LP storage tank shown with transfer system

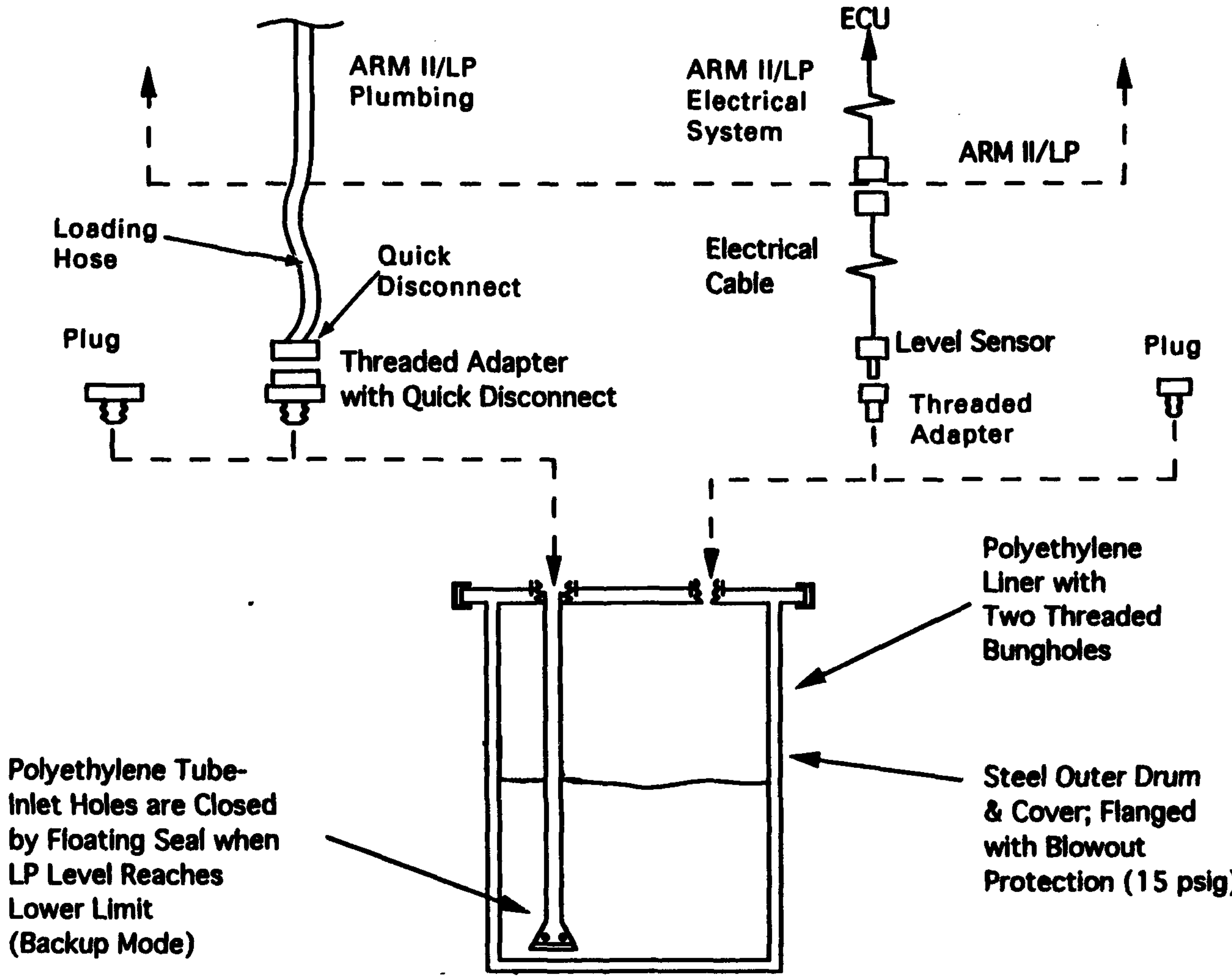


Figure 14. Modifications of HAZMAT drum for bulk LP upload/download

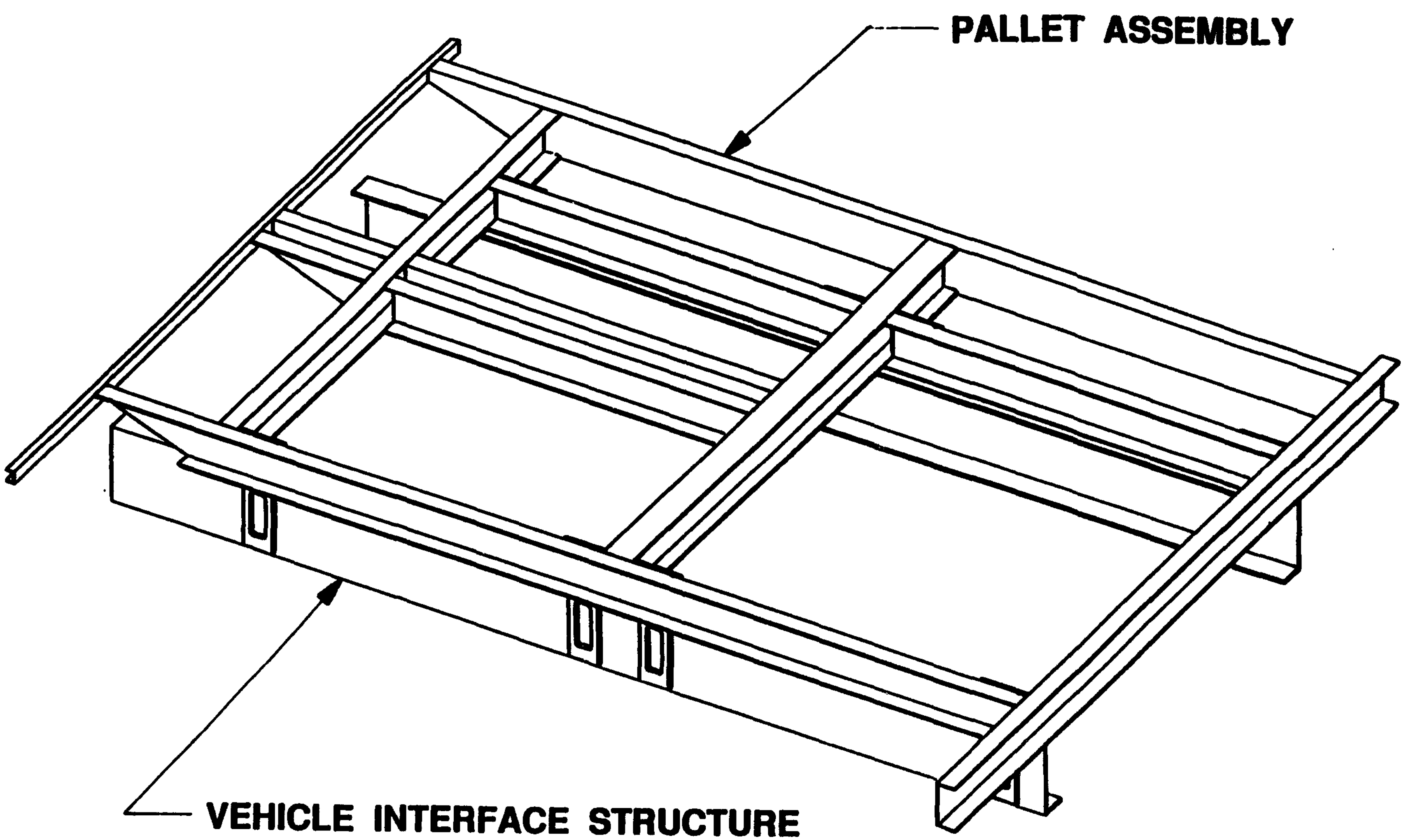


Figure 15. ARM II/LP pallet and structural interface with Bradley chassis

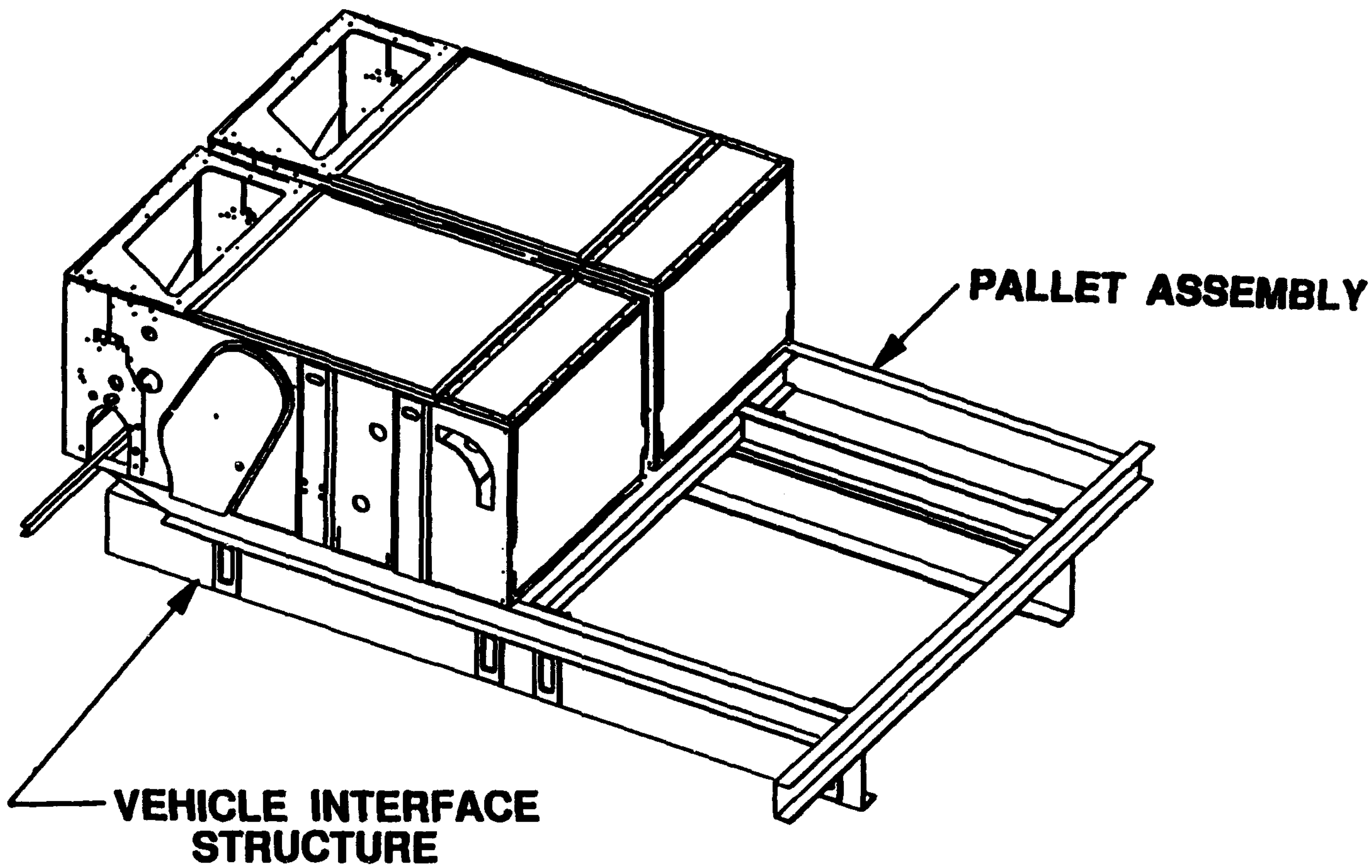


Figure 16. ARM II/LP projectile magazines in side by side arrangement

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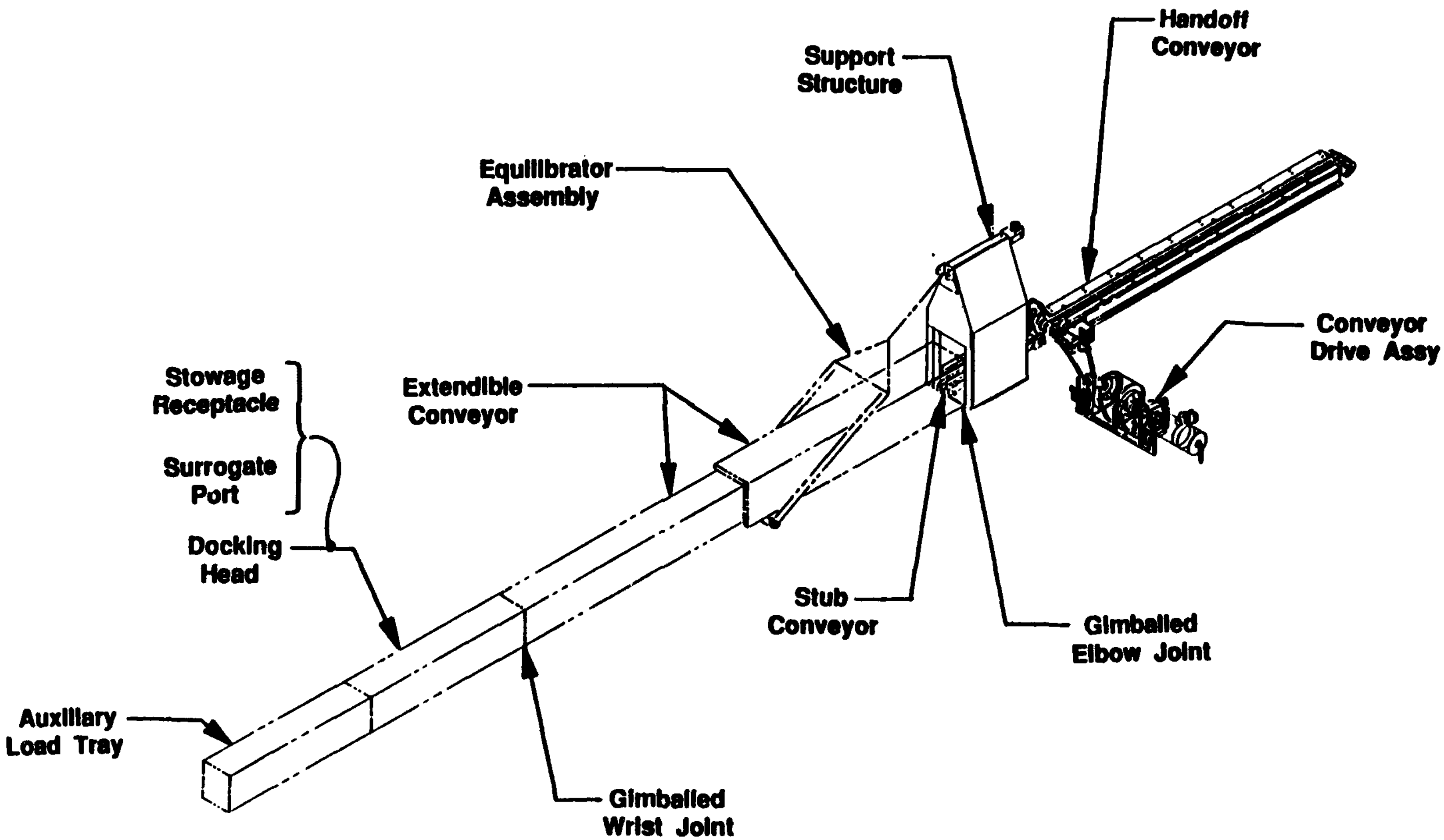


Figure 19. Conveyor system for moving projectiles in and out of the ARM II/LP

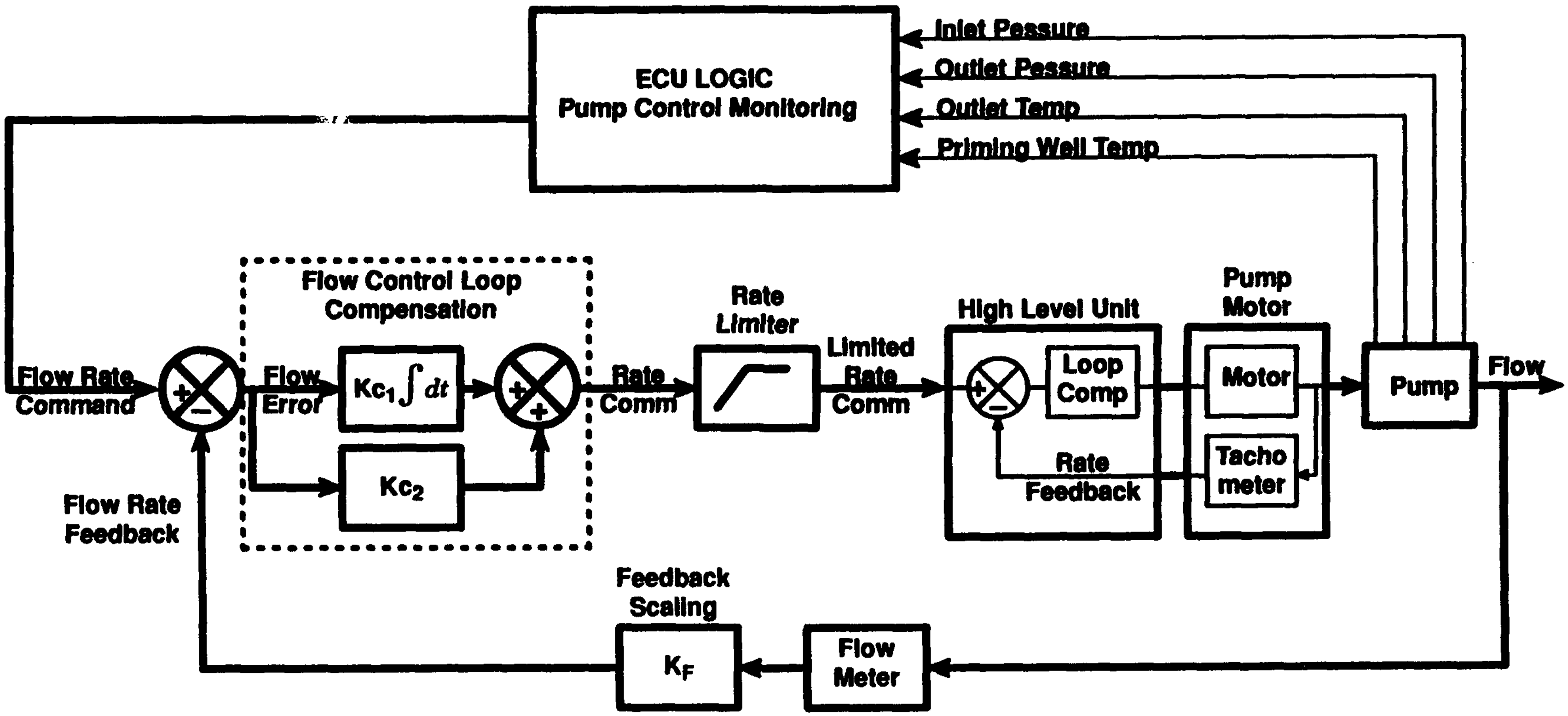


Figure 20. Flow rate control loop for optimum LP download speeds

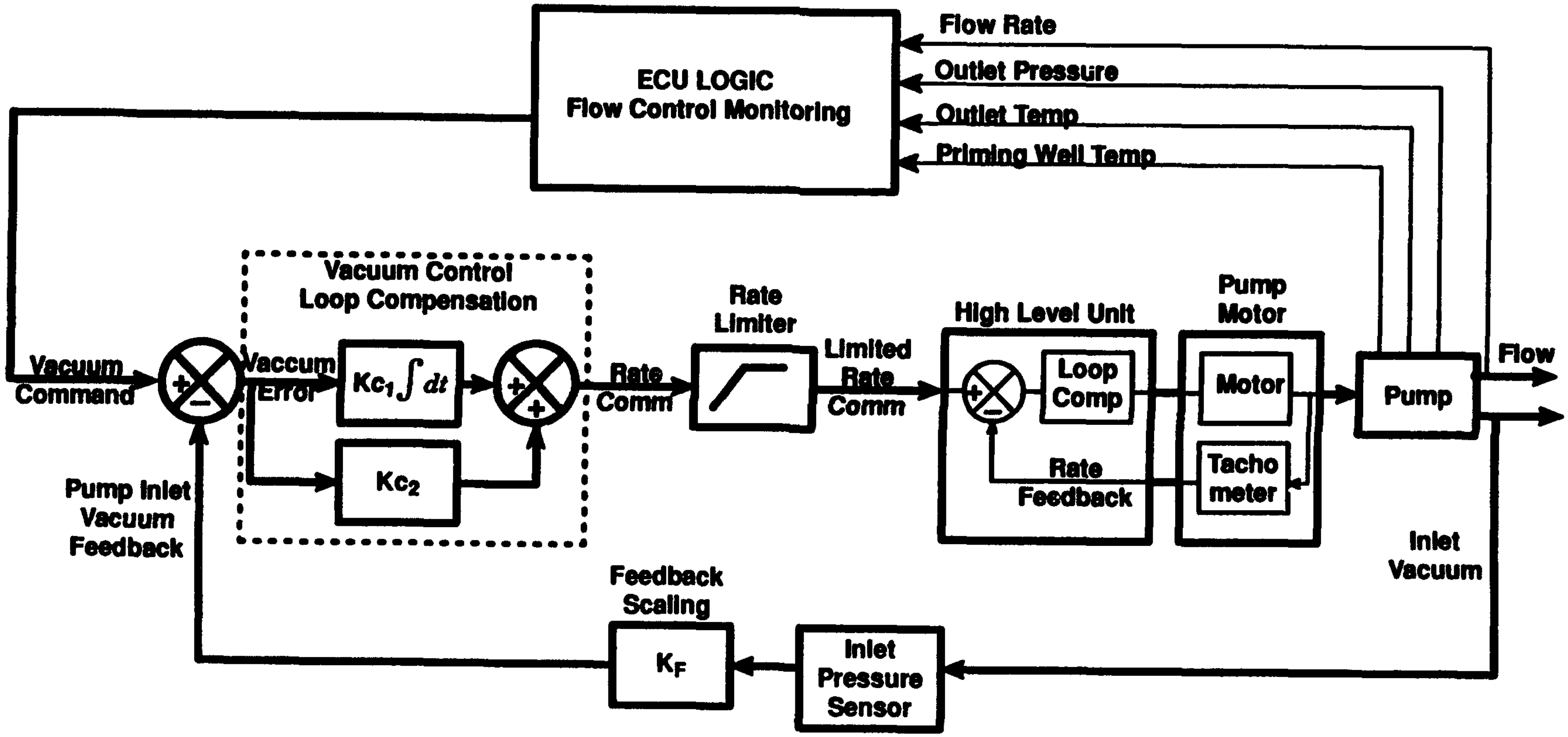


Figure 21. Pump inlet vacuum control loop to optimize upload rate without cavitation

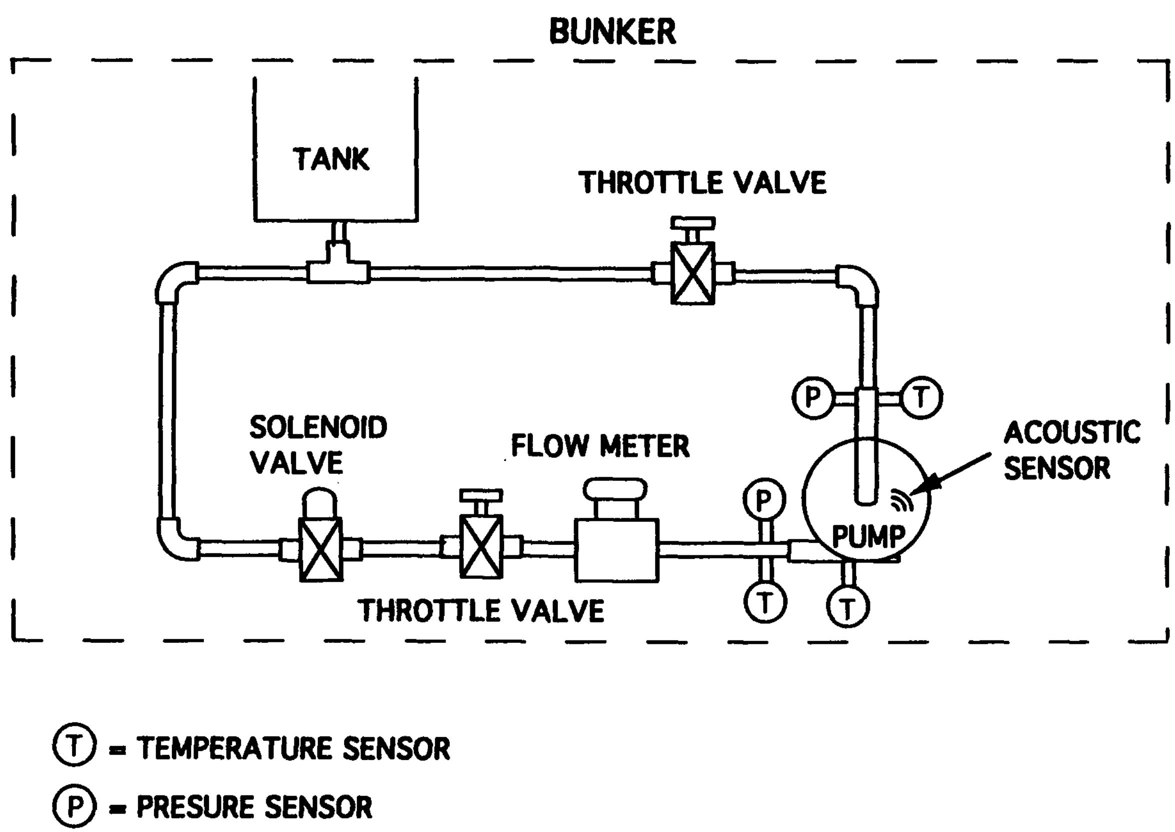


Figure 22. System diagram for LP centrifugal pump characterization test

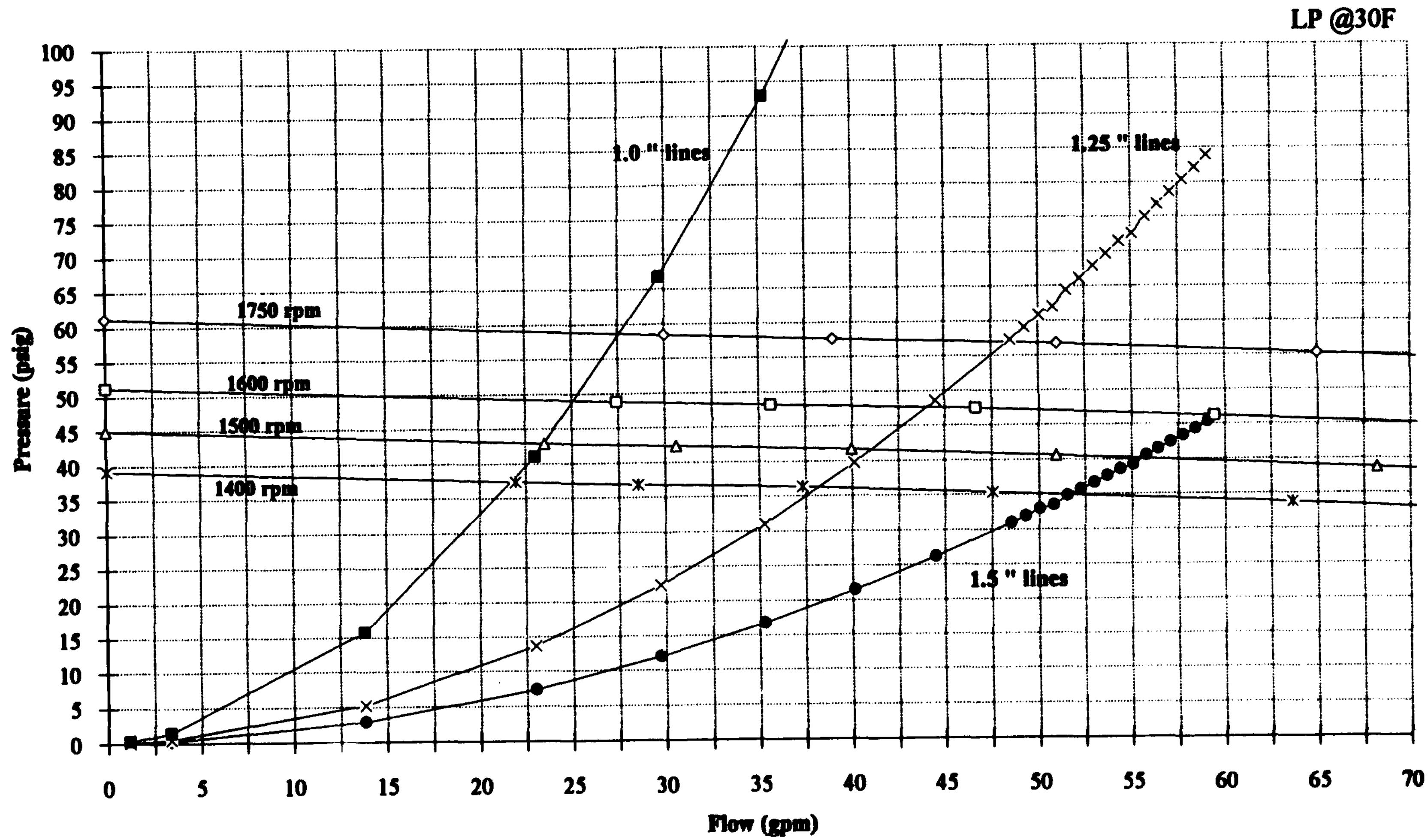


Figure 23. Pressure drop analysis for downloading to surrogate port

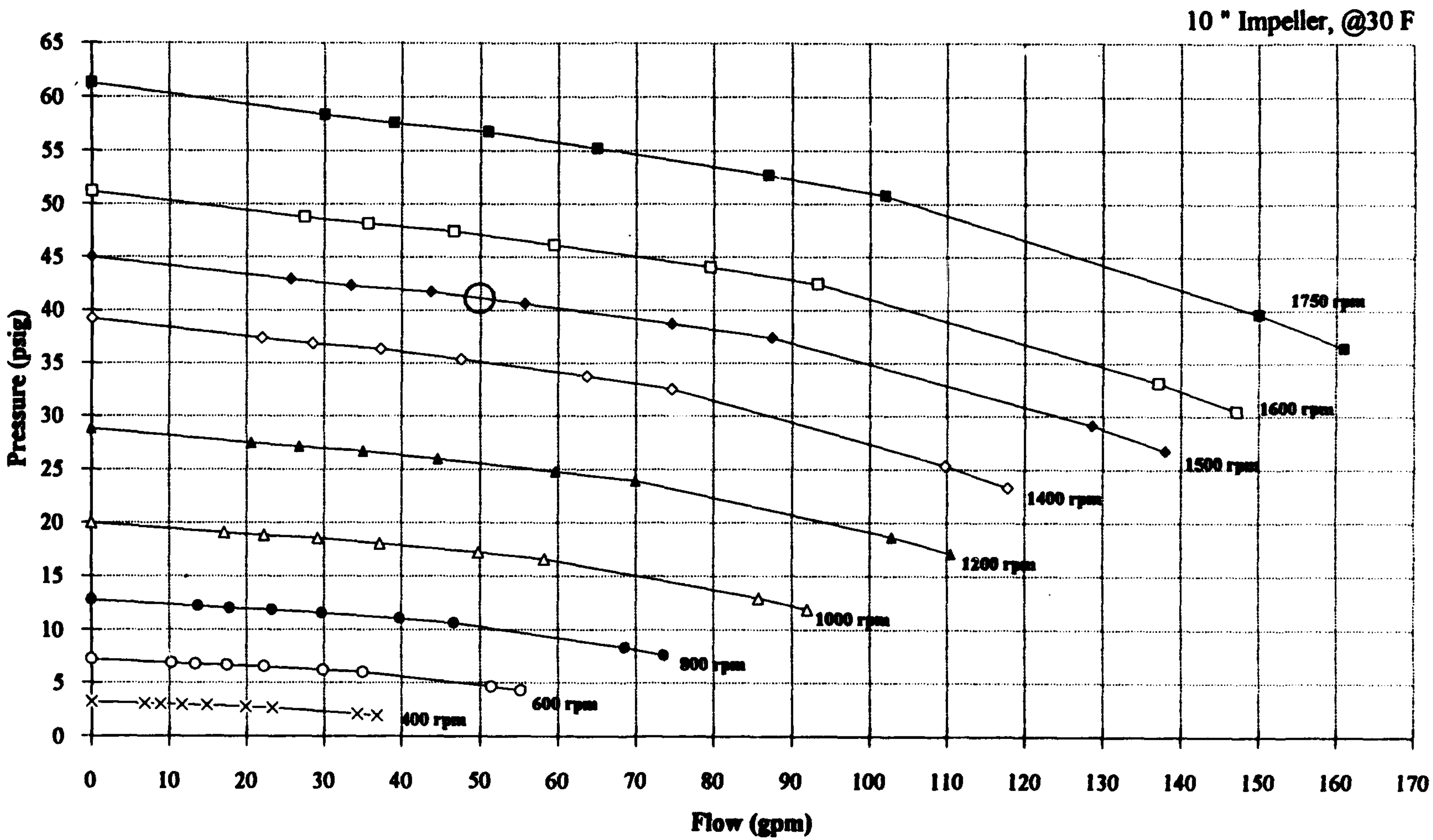


Figure 24. Centrifugal pump performance curves at various impeller speeds

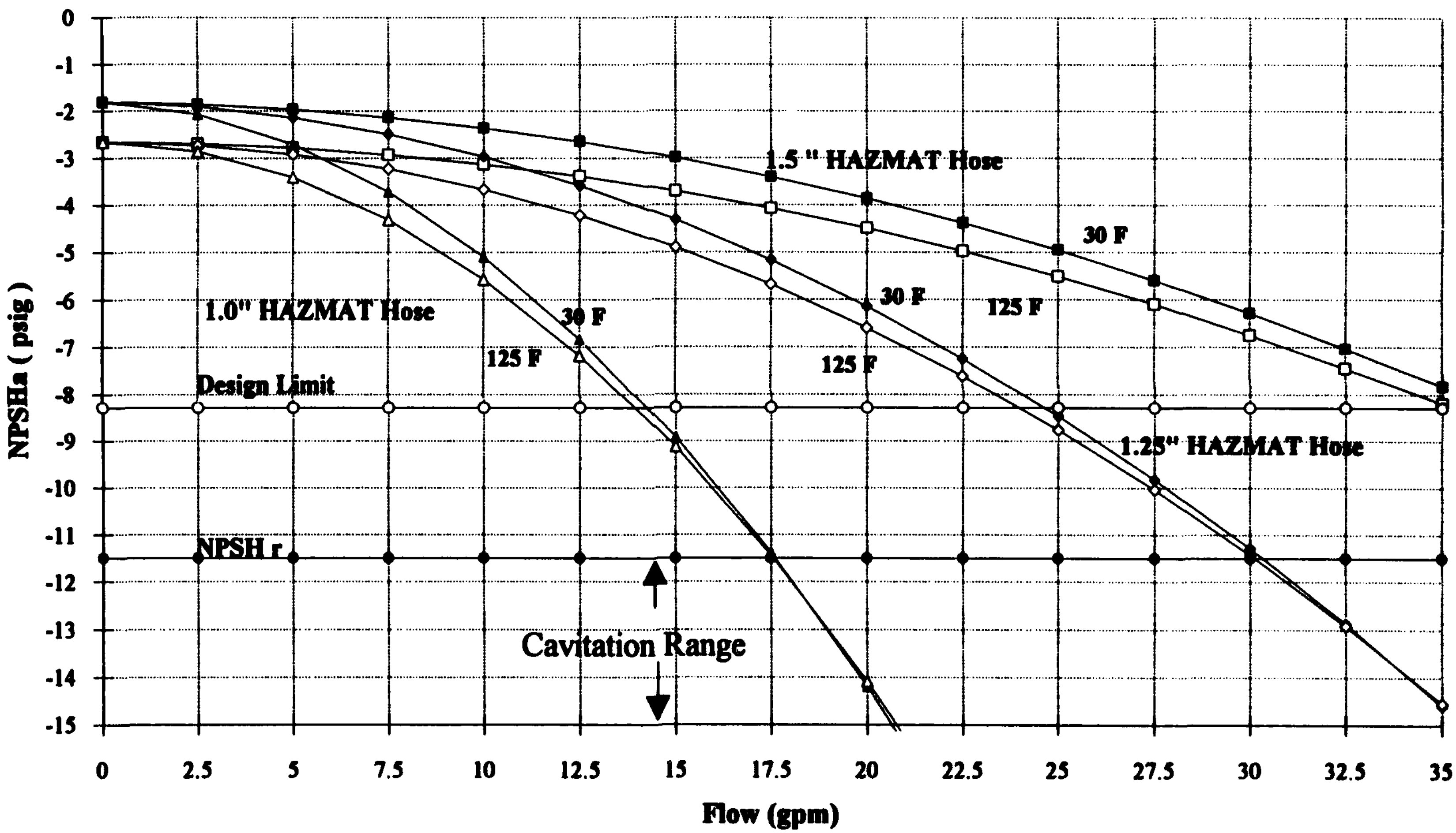


Figure 25. NPSHa versus flow rate and line size for drawing LP out of a HAZMAT drum

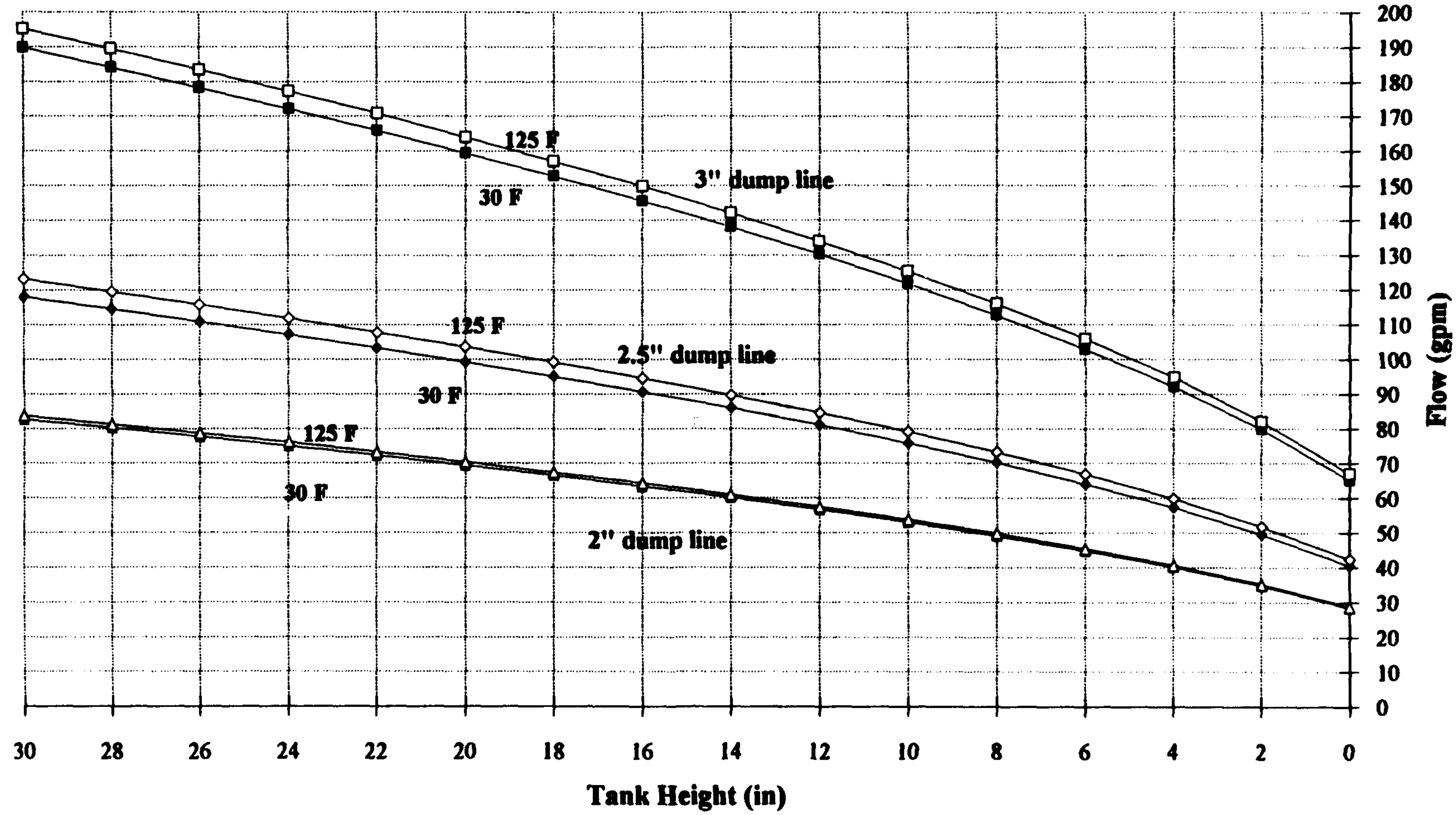


Figure 26. Gravity feed flow rate during emergency dump for various line sizes

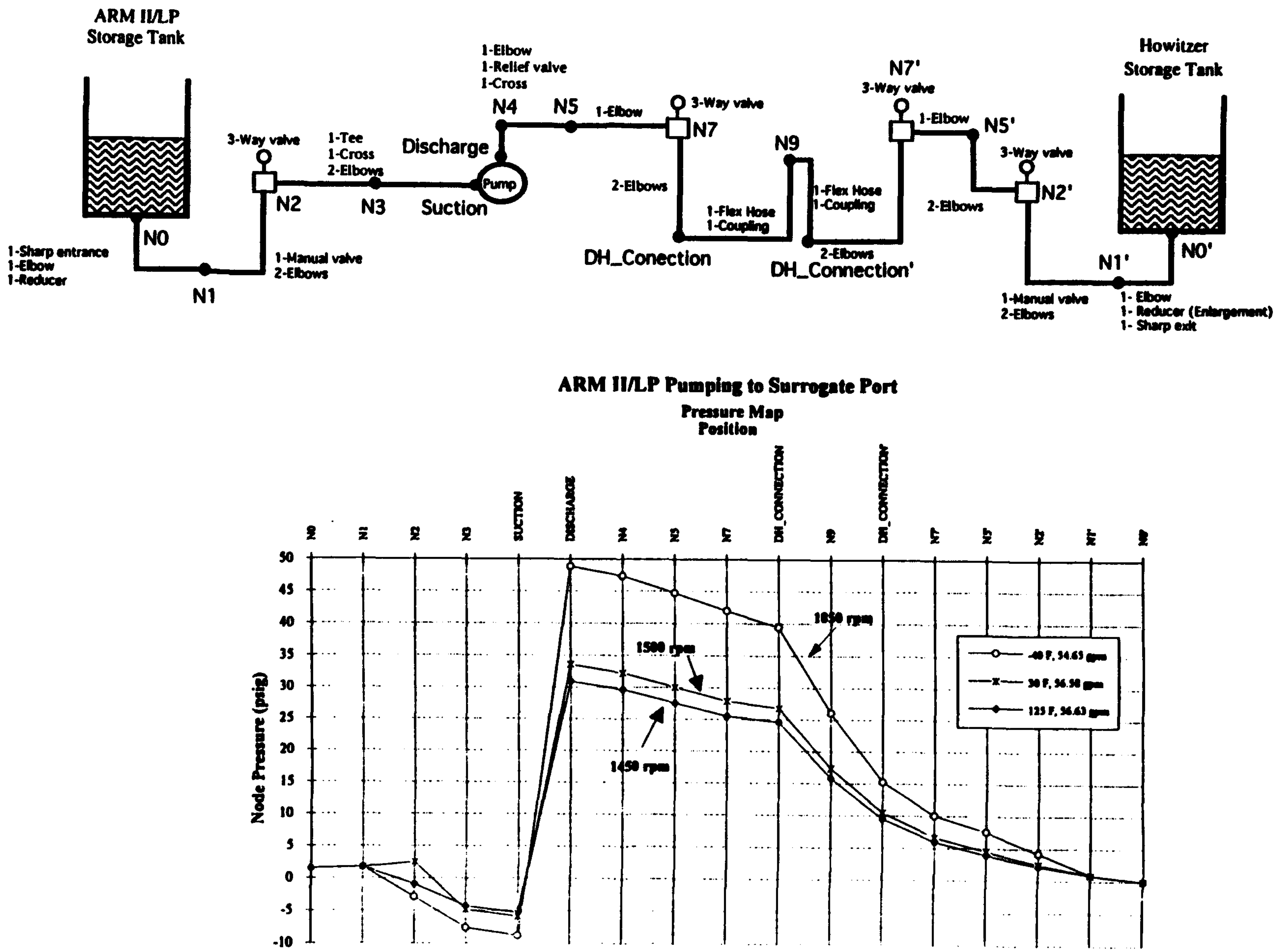


Figure 27. Pressure map analysis for downloading to surrogate port

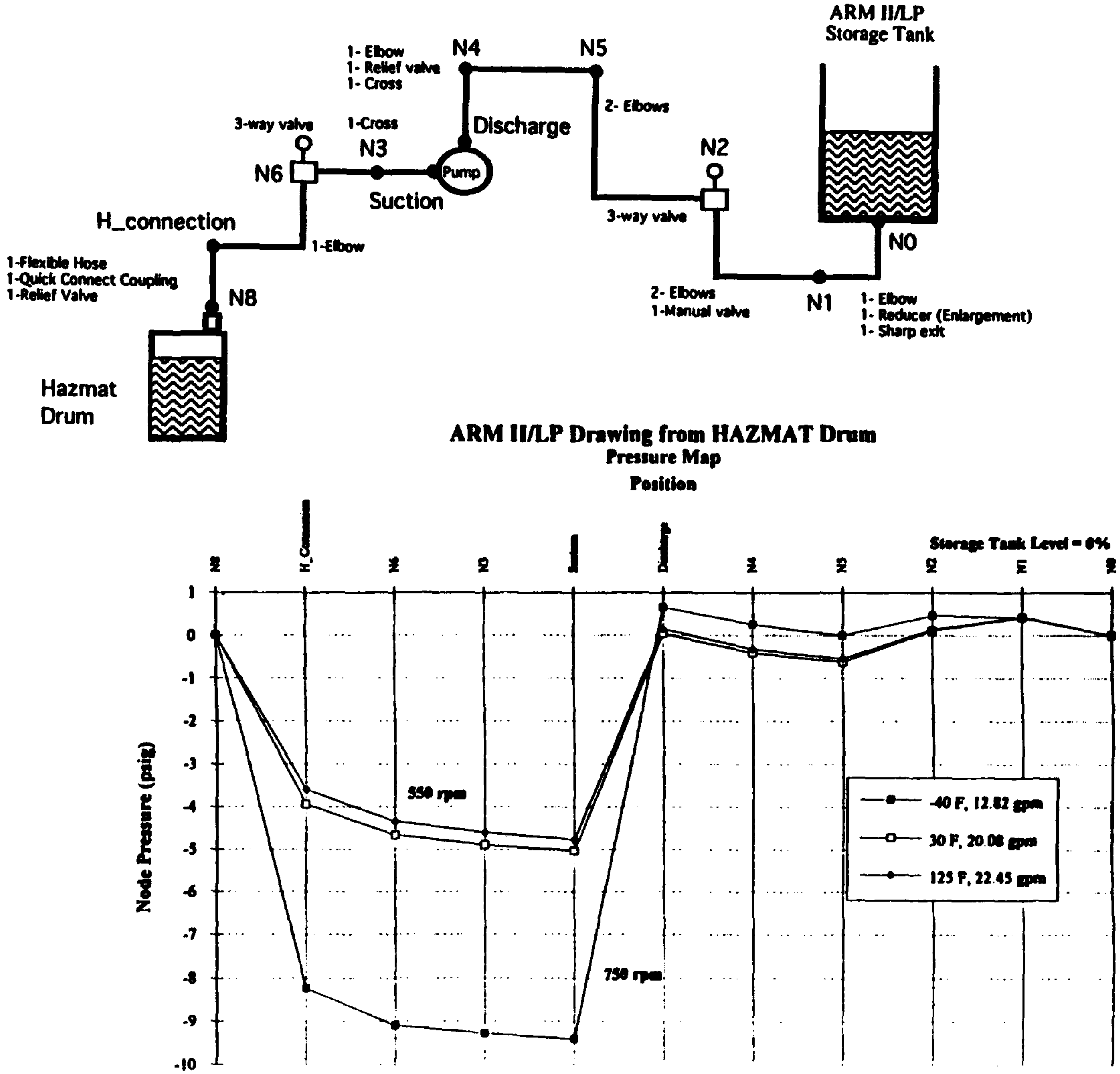


Figure 28. Pressure map for uploading from HAZMAT drums

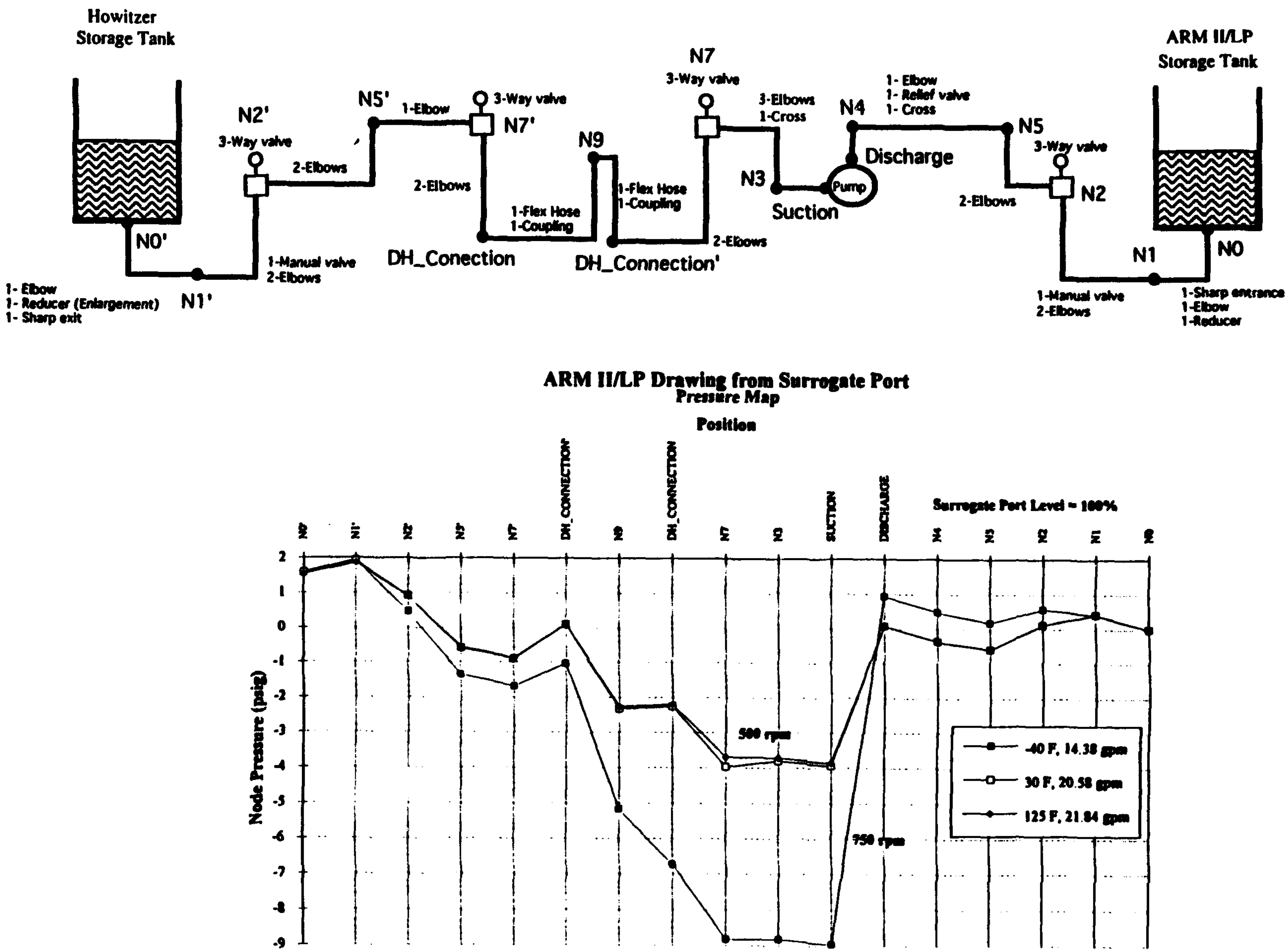


Figure 29. Pressure map for uploading from surrogate port

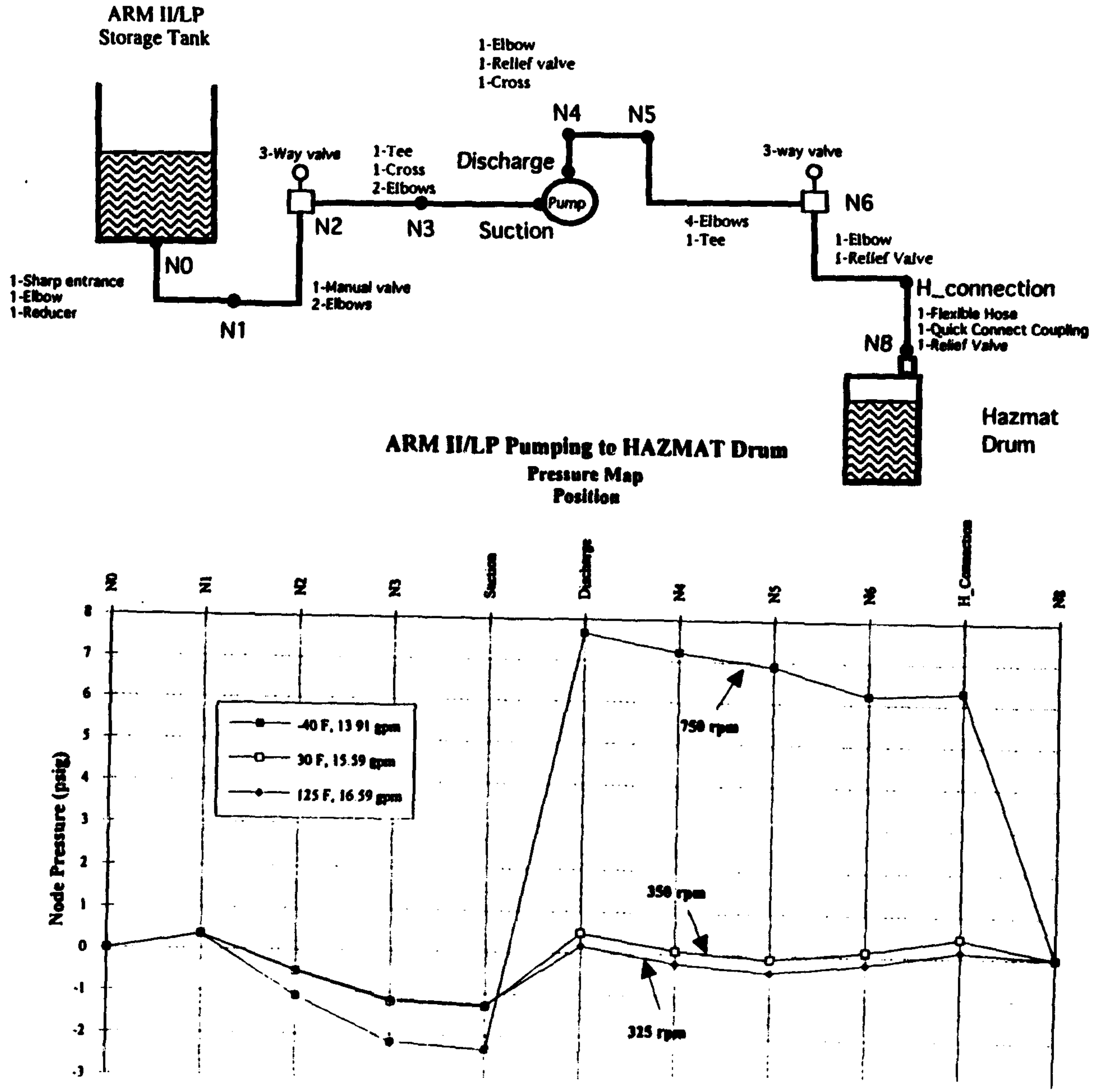


Figure 30. Pressure map for downloading to HAZMAT drums

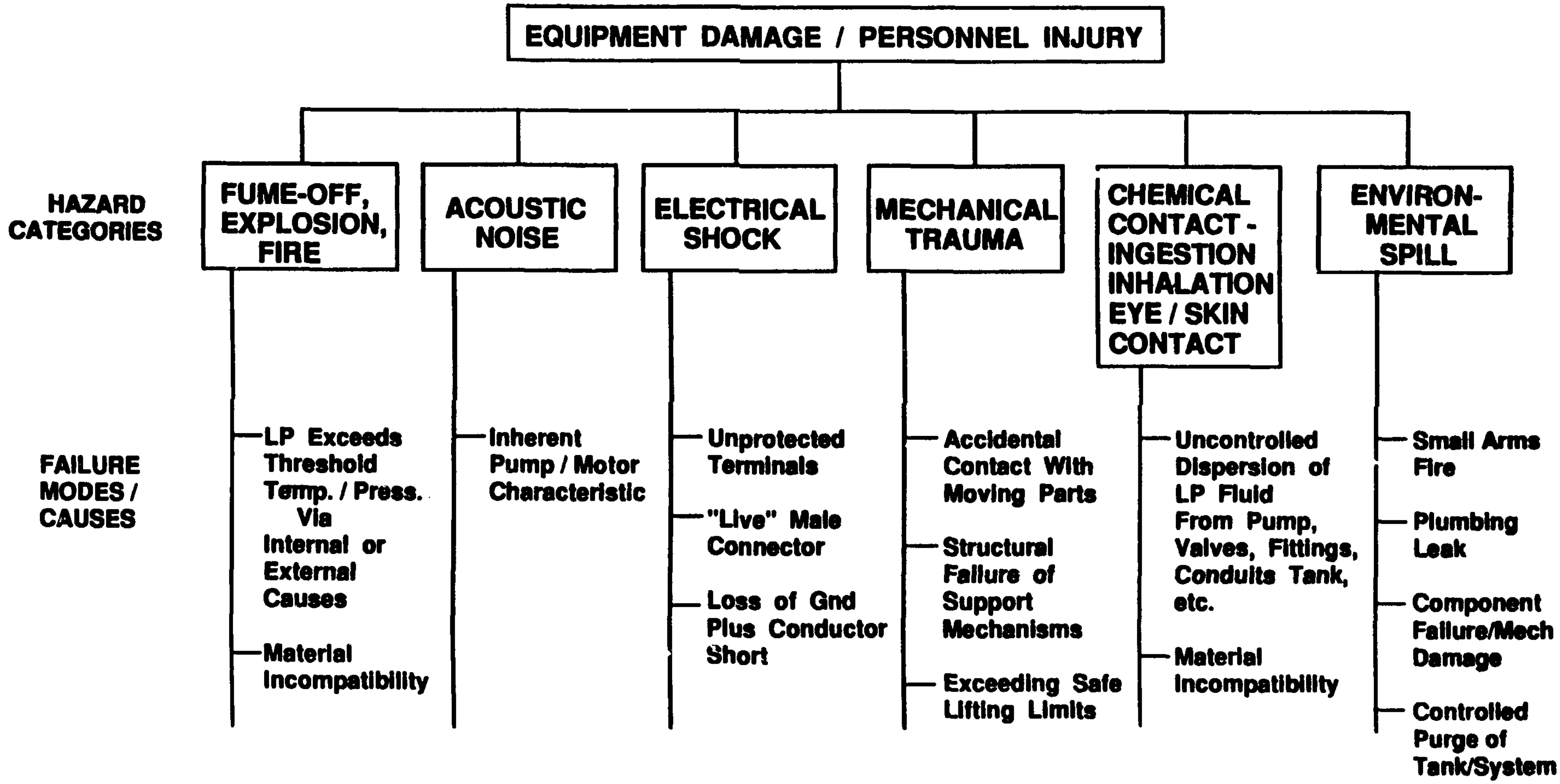
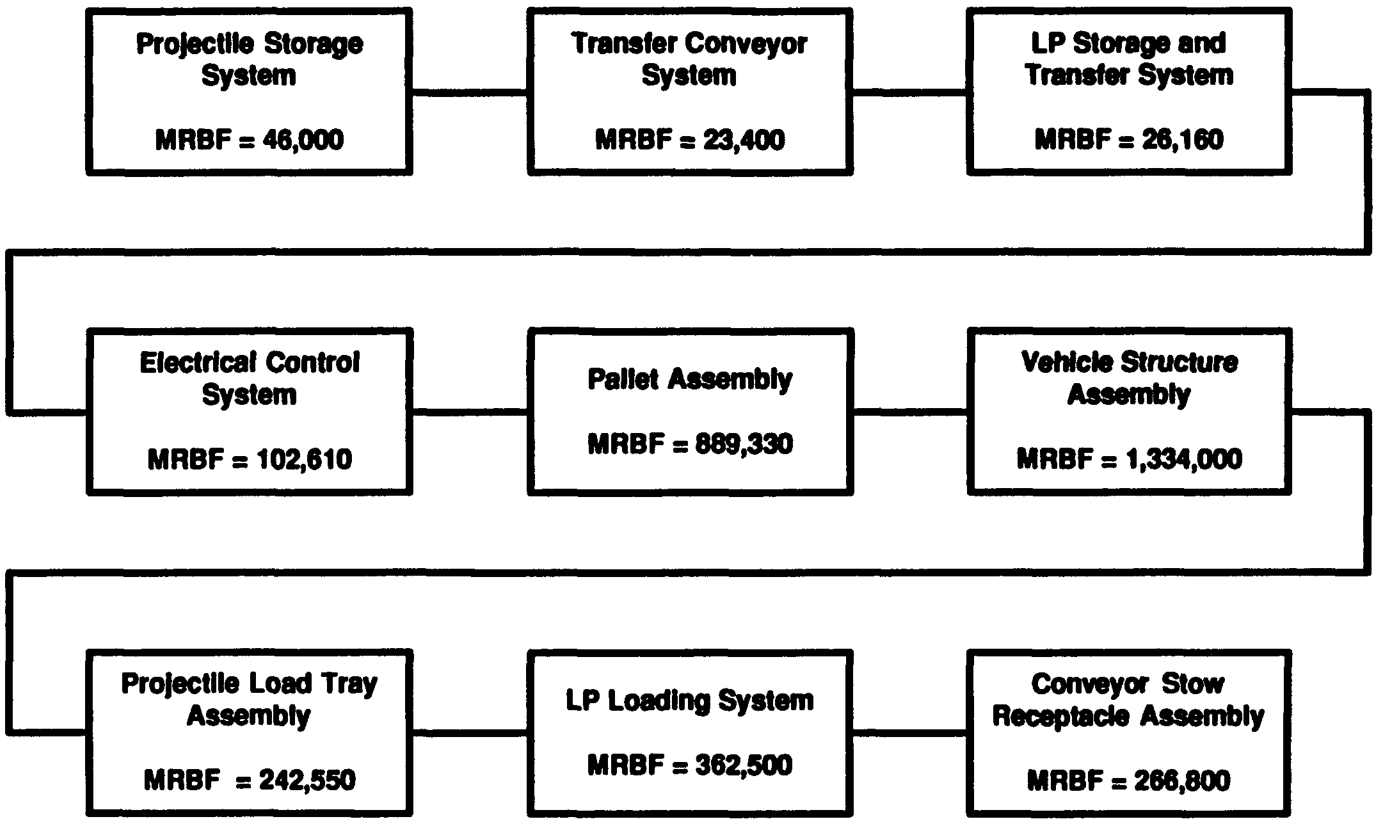


Figure 31. Hazard fault tree for ARM II/LP



ARM II/LP System MRBF = 8,000 Rounds

Figure 32. ARM II/LP reliability block diagram

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1 Gagnon, Joseph N., et al., "155-mm Artillery Rearm Module II, Phase I, Contractor Report ARFSD-CR-92002, ARDEC, Picatinny Arsenal, NJ, March 1992.

2 Liquid Propellant 1846 Handbook, Report No. JPL D-8978 NASA Jet Propulsion Laboratory, Pasadena, CA, March 1992.

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